CHROSOMUS ERYTHROGASTER AND C. EOS (OSTEICHTHYES: CYPRINIDAE): TAXONOMY, DISTRIBUTION, ECOLOGY

A THESIS
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FRONTISPIECE. Male *Chrosomus erythrogaster* in breeding color, headwaters of the Zumbro River, Dodge County, Minnesota, 4 June 1966. Photograph by Professor David J. Merrell of the University of Minnesota.

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INTRODUCTION

Four species of minnows are generally recognized within the North American Genus _Chrosomus_ (Osteichthyes: Cyprinidae): These are _C. eos_ (northern redbelly dace), _C. erythrogaster_ (southern redbelly dace), _C. neogaeus_ (finescale dace), and _C. oreas_ (mountain redbelly dace). _Chrosomus eos_ has been considered a subspecies of _C. erythrogaster_ by some workers (see Jordan and Evermann, 1896:210; Fowler, 1909:520; Legendre, 1952:xi). All of these fishes except _C. oreas_ occur in Minnesota.

The taxonomic, distributional, and ecological relationships of the northern and southern redbelly dace were investigated in the present study. Relegation of these forms to two species is upheld. Their distributions in Minnesota are summarized, chiefly on the basis of collections available at the University of Minnesota. Diet and reproduction were emphasized in the ecological phase of the study, in which _C. erythrogaster_ was studied in detail and compared, when possible, with _C. eos_.

ACKNOWLEDGMENTS

The contributions of the many persons whose assistance made this study possible are gratefully acknowledged. Professor James C. Underhill of the Zoology Department of the University of Minnesota served as my advisor, offered suggestions regarding all phases of the work, and participated in most collecting trips made in the course of the study.

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The investigation of the algal diet of *C. erythrogaster* was done with the help of members of the Department of Ecology and Behavioral Biology of the University of Minnesota. Professor Alan J. Brook made identifications of algae, offered consultation, and critically examined the "DIET" section of the manuscript. Mr. Roscoe F. Colingsworth and Mr. Alden E. Hine generously made and checked identifications of algae.

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SYNONYMY AND NOMENCLATURE

Rafinesque (1820:48) listed "Chrosomus" as a subgenus of the Genus Luxilus when he described C. erythrogaster, but stated: "It might probably form a peculiar genus and be called Chrosomus erythrogaster or Kentucky Red belly." The type specimen(s) came from the Kentucky River, with no one locality specified.

Cope, who brought the name "Chrosomus" into general use, distinguished C. eos from C. erythrogaster (1862: 523) on the basis of specimens from Meshoppen Creek, Susquehanna County, Pennsylvania. He listed several features that he considered diagnostic, perhaps the most significant of which are the comparatively more oblique mouth and shorter snout in C. eos.

Cope later again discussed differences between C. erythrogaster and "C. eos" (1864:281), but confused C. eos with the yet-undescribed C. neogaeus and actually gave characteristics pertinent to the latter. He subsequently acknowledged this error (1869a:375), and, on the basis of specimens taken at New Hudson, Livingston County, Michigan, named C. neogaeus as Phoxinus neogaeus (p. 374). In the same year, he named Chrosomus oreas from specimens apparently taken in Montgomery County, Virginia (1869:233-4).

Jordan, in the first edition of his "Manual of the vertebrates of the United States ... " (1876:284), recognized three species of *Chrosomus*: *C. pyrrhogaster*, *C. erythrogaster*, and *C. eos*. Of these three, only *C. eos* was in synonymy with its original description. Jordan named *C. pyrrhogaster* as a new species and stated that it was not the *C. erythrogaster* of Rafinesque. I can find nothing in his diagnostic description to support this assertion. Jordan considered his *C. erythrogaster* to be the same fish as Cope's *C. oreas* (*loc. cit.*). Thus it seems clear that Jordan's *C. pyrrhogaster* is referable to *C. erythrogaster*, and his *C. erythrogaster* is referable to *C. oreas*.

In the second edition of "*Manual of the vertebrates* ...", Jordan (1878:302) listed only *C. erythrogaster* under "*Chrosomus*" and stated: "There seems to be but one well-defined species." However, Jordan and Gilbert (1882:153-4) listed *C. erythrogaster*, *C. eos*, and *C. oreas* as separate species. This arrangement remained rather stable, although *C. eos* has been regarded as a subspecies of *C. erythrogaster* by certain workers and *C. neogaeus* was added to the genus later.

The finescale dace was called *Phoxinus neogaeus* until Jordan (1924:71) assigned it to a 'new' genus, *Pfrille* (which, he stated [*loc. cit.*] "is the German name of *Phoxinus phoxinus*").

The circumstances under which "*Pfrille*" was placed in the Genus *Chrosomus* are obscure. Regarding this action, Professor Reeve M. Bailey, curator of fishes at the University of Michigan stated (personal communication, 29 August 1967):

> "I am not sure who first assigned neogaeus to the genus Chrosomus but for want of an earlier date I may refer you to its positioning in that genus by C. L. Hubbs (1955, Systematic Zoology, Vol. 4, No. 1, p. 10). It was my conclusion after examination of the generic status of American freshwater fishes in 1949 that this action should be taken and Dr. Hubbs was aware of this belief. However, I do not recall having referred to the species in question during the interval between 1949 and 1955. It is entirely possible that someone else made the shift earlier. Many people have adopted the shift in generic names [Pfrille to Chrosomus]. Most recently Banarescu in a book on the fishes of Roumania has gone one step further and synonymized both Chrosomus and Pfrille in the genus Phoxinus which genus had formerly been thought to be confined to the Old World. To my knowledge no American worker has yet followed this latter action but that is perhaps due to the fact that few are aware of it."

The generic name Chrosomus will be retained in the ensuing discussion of the North American members of the "Phoxinus-Chrosomus complex".

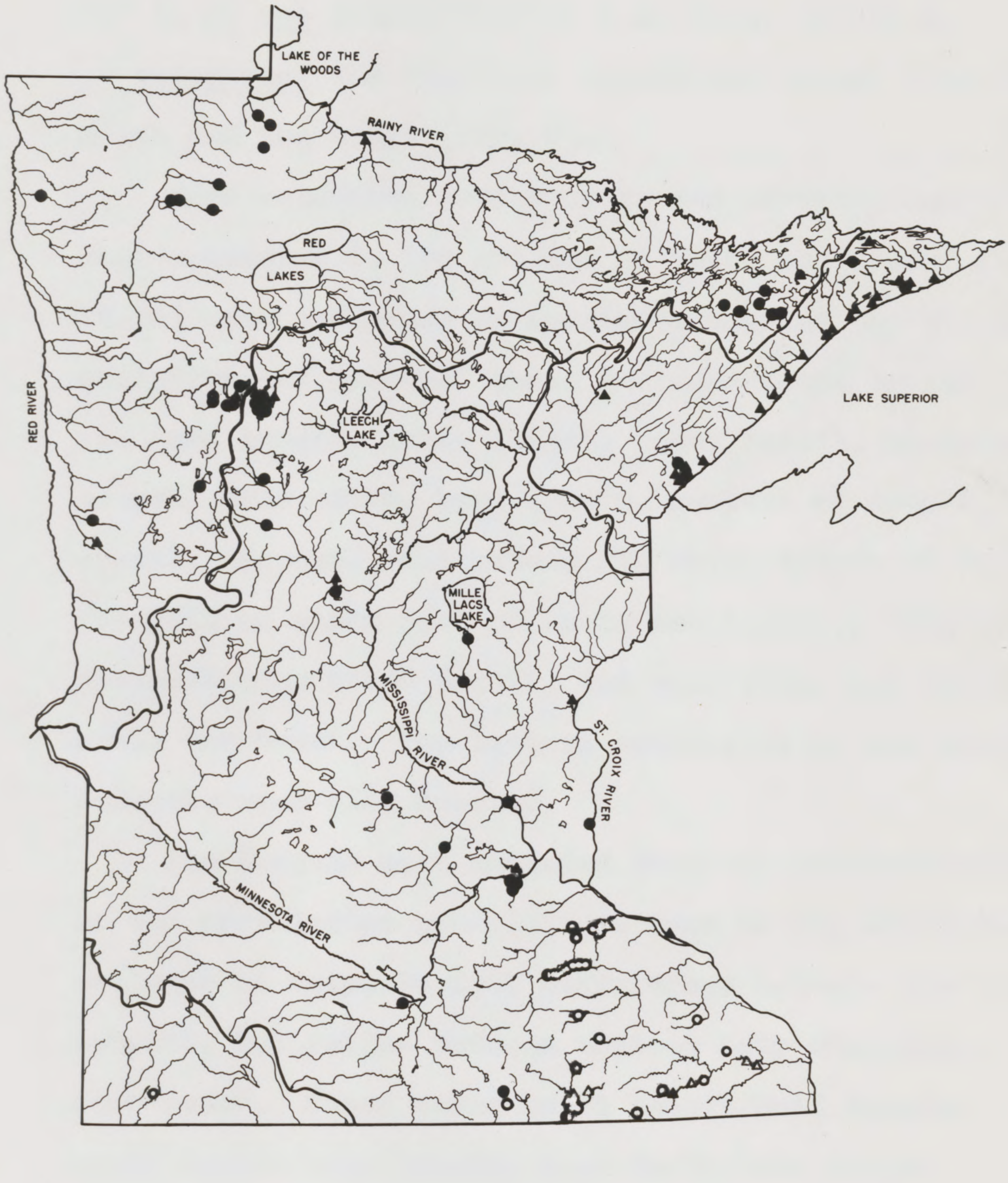
METHODS AND MATERIALS

The collections of *Chrosomus erythrogaster* and *C. eos* upon which the present study was based were either taken in the course of the investigation by seining or were available in the James Ford Bell Museum of Natural History at the University of Minnesota. Unless otherwise identified, collection numbers refer to those housed in the fish collection at the Museum.

All specimens in the available collections were examined under a Unitron dissecting scope at a magnification of 12X and identified according to the author's criteria. Identifications of some specimens in the University's catalogued collections were changed, and a list of the collections, arranged in numerical order and giving original and revised identifications, was compiled (see APPENDIX). From these identifications the distributions of *C. eos* and *C. erythrogaster* in Minnesota were established (Fig. 1). These distribution patterns were used in making inferences about the interrelationships of the two species and as guides in choosing specimens used for statistical analyses.

The characters relied upon most to distinguish between the two species were the "angle of mouth", measured with a flexible aluminum protractor "between the edge of the premaxillary and the line approximately

FIG. 1. Map showing the localities where collections of *Chrosomus eos* and *C. erythrogaster* examined in the present study were taken. Closed circles denote *C. eos*, localities precisely known; closed triangles, *C. eos*, localities not precisely known; open circles, *C. erythrogaster*, localities precisely known; open triangles, *C. erythrogaster*, localities not precisely known; and half closed circles, both species together, localities precisely known.


LAKE OF THE WOODS
RAINY RIVER
RED LAKES
RED RIVER
LEECH LAKE
LAKE SUPERIOR
MILLE LACS LAKE
MISSISSIPPI RIVER
ST. CROIX RIVER
MINNESOTA RIVER

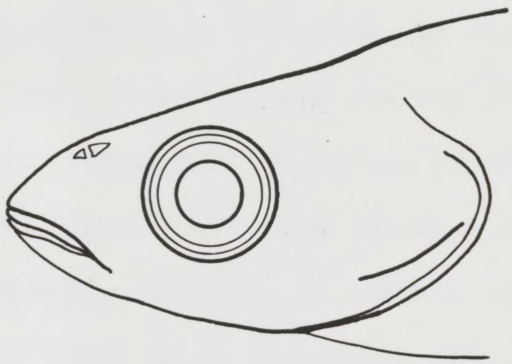
tangential to the top of the profile of the head (Hubbs, 1946:79)", and the relative lengths of orbit and snout. These characters varied with the individual. However, among adults in Minnesota the angle of mouth averaged 50° in _C. erythrogaster_ (range 44-58°; s.d. 2.6) and 60° in _C. eos_ (range 51-66°; s.d. 2.8), and in _C. erythrogaster_ the snout was relatively longer than the mouth and the orbit (Fig. 2).

More extensive measurements and meristic counts, made according to the methods of Hubbs and Lagler (1958: 19-26) were performed on specimens used in the studies of variation and growth. These included total length, standard length, orbit length, snout length, postorbital length, head depth, head length, numbers of dorsal, anal, caudal, pectoral, and pelvic fin rays, length of mouth ("length of upper jaw" of Hubbs and Lagler), lengths of pectoral, depressed dorsal, and anal fins, and lateral scale row count. The lateral scale rows on the caudal peduncle were also counted.

Fin lengths were excluded from the determinations of the correlation coefficients used in the statistical analyses of morphological differences between the two species, but ratios between various body dimensions were added. These were: Snout length/head length, orbit length/head length, head depth/head length, mouth length/head length, orbit length/snout length, mouth length/snout length, head length/standard length, snout length/postorbital length, and snout length/head

FIG. 2. Drawings of head of a specimen of *Chrosomus eos* (top), total length 53.9 mm, from headwaters of Mississippi River, Clearwater County, Minnesota, 22 June 1964, and head of a specimen of *C. erythrogaster*, total length 60.8 mm, from Otter Creek at County Road 6, Mower County, Minnesota, 24 October 1964.

C. eos



C. erythrogaster

depth.

The sample used to supply data to the computer for determinations of correlation coefficients was composed of 115 specimens of each species (Table 1). These specimens are housed at the Natural History Museum or the Zoology Building, University of Minnesota.

The samples were assembled so that variability within each species was maximized for both size of individuals and variety of drainage systems within the limits of the material at hand. Attempts were made to (1) represent all size classes as equally as possible in each drainage system, (2) represent all drainages as equally as possible, and (3) represent both species equally in all size intervals. As Table 1 shows, an ideal balance was not attained, because specimens needed to fill certain gaps were simply not available. For example, only three C. eos in the 70-80 size range were found. Thus the 70-80 mm interval was less-well represented than the other sizes. Furthermore, if a balance between species in number of specimens in each size range were to be realized, it was necessary to include only three C. erythrogaster in the 70-80 mm range despite the presence of many C. erythrogaster of this size in the collections.

The data accumulated for all 230 specimens were punched on standard data cards and fed into a Control Data Corporation 6600 computer programmed for

TABLE 1. Summary of sizes and localities of specimens used to derive an intercharacter correlation matrix for comparing the external morphology of *Chrosomus erythrogaster* with that of *C. eos*, based on specimens from Minnesota. (A -- *C. erythrogaster*).

A. *C. erythrogaster*

DRAINAGE (or river basin)	Total length intervals (mm)						TOTAL SPECIMENS
	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-80	
($\bar{X}$)	(27.5)	(35.1)	(45.4)	(55.1)	(63.9)	(75.0)	
Cedar River	1* **	7**	6	11	5	0	30
Missouri River	0*	0*	7*	0*	0*	0*	7*
Mississippi, lower							
A. Cannon River	2* **	8* **	5*	2*	0*	3*	20*
B. Root River	0*	0*	7*	6*	15*	0	28
C. Zumbro River	4* **	5**	5	11	5	0	30
TOTAL SPECIMENS	7* **	20	30	30	25	3	115

* "Obligatory number" -- No more specimens available.

** -- Identified by "faunal association" with larger *C. erythrogaster*.

TABLE 1 (Continued). B. *C. eos*.

DRAINAGE (or river basin)	Total length intervals (mm)						TOTAL SPECIMENS
	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-80	
($\overline{X}$)	(28.4)	(37.8)	(45.8)	(53.8)	(63.8)	(71.2)	
Arctic	4*	5	5	5	4*	1*	24
Cedar River	0**	0**	0*	4*	0*	0*	4
Minnesota River	0*	0*	4*	5	6	2*	17
Mississippi, lower	0*	0**	6	2*	2*	0*	10
Mississippi, upper	0*	5	5	5	3*	0*	18
Red River	0*	5	5	5	5	0*	20
Superior	3*	5	5	4	5	0*	22
TOTAL SPECIMENS	7	20	30	30	25	3*	115

* "Obligatory number" -- No more specimens available.

** "Obligatory number" -- Could not be distinguished from *C. erythrogaster* in the size ranges indicated.

intercharacter correlation coefficient determination by the University's UMSTAT program (Pearson product moment correlation -- see, for example, Hammond and Householder, 1962:188).

The ecological phase of the study was based on field observations of _C. eos_ in and around Itasca Park in Clearwater County, on similar observations of _C. erythrogaster_ in the headwaters of the south branch of the Zumbro River in Dodge County, and on preserved specimens collected during the investigation. Studies of reproduction and diet were done chiefly with _C. erythrogaster_.

Specimens used in the study of sexual cycles were preserved in formalin in the field and transferred to 50% isopropyl alcohol after one week. Preserved total weights and weights of gonads were determined on a Mettler Balance. Excess moisture was removed from each specimen and from its excised gonads with absorbent paper towels prior to weighing.

Specimens for the diet study were either preserved in formalin in the field or transported alive to the University of Minnesota for observational and experimental aquarium studies.

The natural diet of _C. erythrogaster_ was analyzed in relation to (a) season and (b) time of day. The seasonal study was conducted with specimens collected on 10 occasions from 20 April through 12 November 1966. Minnow traps were placed in the stream in December, 1966, and in January and February, 1967, in hopes that the study might encompass these months as well, but no *C. erythrogaster* were captured. Planktonic, epiphytic, and epilithic algae were collected on 21 May, 24 July, and 25 September.

A sample study to give some insight into daily feeding activity was done with specimens taken in the study area at 4-hour intervals from 9:30 PM, 15 May, through 5:30 PM, 16 May, 1967. Planktonic and epiphytic algae were also collected.

Planktonic, epiphytic, and epilithic algae were placed in vials and refrigerated until examined. They were preserved with a few drops of formalin if they were not analyzed within a week after being collected. Fishes were transferred from formalin to 50% isopropyl alcohol one week after being collected.

Algae were viewed under a light microscope using a magnification of 593.75X. Keys used to identify algae were those of Hohn (1951), Hustedt (1930), Patrick and Reimer (1966), and Prescott (1962 and 1964). The system of classification followed is essentially that of Smith (1950).

After the total length of each fish was measured, the dietary components were prepared and analyzed as follows:

(1) The digestive tract between pharynx and anus was removed from the body and from it three sections, each 20 mm long, were taken. These three sections were from the anterior, middle, and posterior portions of the tract, respectively.

(2) Each 20-mm section was placed in a vial with 1 ml distilled water and macerated until its contents were released into the medium. The contents of digestive tracts appeared as a dark brown, amorphous mass, and formed a suspension of similar color. The vials were numbered "1" (anterior 20-mm section), "2" (middle 20-mm section), and "3" (posterior 20-mm section).

(3) A drop of the suspension from vial 1 was transferred by an eyedropper onto a hemocytometer that supported a water film 0.2 mm deep when under a coverslip. The first 167 identifiable algal organisms seen were counted. The hemocytometer and coverslip were cleaned, a drop from vial 2 was placed on the hemocytometer, and again 167 algal organisms were counted. The same procedure was followed with vial 3, but now 166 were counted. Thus 500 algal organisms were counted per fish (167 + 167 + 166 = 500). The number 500 was selected arbitrarily.

Sometimes the absence of food in the anterior part of the intestine allowed use of 20-mm sections from only the middle and posterior regions of the intestine. When it was necessary to use such a fish due to lack of specimens with fuller intestines, 500 algal organisms were tallied by counting 250 apiece from vials 2 and 3.

Temporary mounts such as those used here have two advantages over permanent mounts: The latter require more time to prepare, and, if permanent mounts designed to identify diatoms (the most common food items observed) are made, other algae present are destroyed in the process. The main disadvantage of temporary mounts is that they do not adapt well to the high resolutions sometimes needed to identify diatoms.

Time limitations and a desire to study the entire diet necessitated the use of temporary mounts. An average of 30 algal organisms per 20-mm section, chiefly diatoms that were fragmented or in a position that made identification difficult (e.g., "girdle view"), or "soft" algae that were damaged, remained unidentified.

Ten permanent slides of diatoms were prepared to confirm identifications. These were made by boiling diatoms in concentrated nitric acid and potassium dichromate to "clean" them, and mounting them in Hyrax liquid medium (refractive index 1.65).

The 20-mm sections were taken from different places in the alimentary canal to (a) see if dietary contents varied in different parts of the tract of an individual fish, and to (b) determine, if possible, where digestion occurred.

Regarding the use of the "number method" (see Hynes, 1950:36) for analyzing the composition of the diet, it seemed that this method was best under the circumstances. Hynes reviewed literature on methods of analyzing diets of fishes, pointing out advantages and weaknesses of each. He favored the "points method" adapted from Swynnerton and Worthington (1940), in which food organisms were alloted a number on the basis of size and estimated abundance. Then "... the points gained by each food item were summed and scaled down to percentages, to give percentage composition of the food of all the fish examined (Hynes, pp. 36-7)." Hynes (p. 40) rejected the "number method" for small fishes such as those I studied, which consume large numbers of small organisms. The "number method" was nevertheless employed here, for the following reasons:

(1) Due to my apparent inability to make accurate subjective evaluations of the relative numbers of organisms present, the "points method" seemed to give a misleading picture of the diet in specimens for which this kind of analysis was attempted. Counts performed on the same fish indicated that numbers of relatively large items were generally overestimated, while numbers of smaller organisms were often underestimated.

(2) Hynes' discussion centered on fishes that eat organisms (such as arthropods and mollusks) that are much larger than those consumed by the minnow studied here. Evaluation of dietary items according to volume is important, and is feasible when they are large and occupy a substantial portion of the volume of the gut. Items of nutritional value occupied but a small part of the digestive tract in the C. erythrogaster examined due to the presence of much inorganic debris. This fact and difficulties in satisfactorily alloting volumetric points to the tiny organisms eaten led me to rely solely upon numbers to describe the composition of the diet.

Algal colonies and filaments were counted as single individuals just as were unicellular forms. Obviously, an ingested strand of a filamentous alga could be but part of the parent plant, and it was furthermore not possible to tell to what extent colonies and filaments were fragmented when consumed (a weakness of the "number method" also mentioned by Hynes, p. 37). Organisms preserved while dividing were also counted as one individual.

Counting each cell in multicellular algae seemed unnecessary but the average number of cells in the commonly-eaten multicellular forms Oscillatoria and Gomphosphaeria (Division Cyanophyta) were estimated.

50 randomly-selected strands of *Oscillatoria* averaged 118 microns in length, 10 microns in width (as determined with an ocular micrometer), and contained an average of 34 cells. 50 randomly-selected colonies of *Gomphosphaeria* averaged 19 microns in length, 15 microns in width, and contained an average of 15 cells.

The daily cycle of feeding activity of the *C. erythrogaster* collected at 4-hour intervals on 15-16 May 1967 was judged by visually estimating the amount of food present in the intestines of 20 specimens per sample. This method has the disadvantage that it depends entirely on the observer's subjective judgment. However, since attempts to weigh the contents of digestive tracts were time consuming, and, due to practical difficulties, inaccurate, the faster visual estimate was performed.

DISTRIBUTION

Geographical Distribution.

The geographical distribution of *Chrosomus eos*, as summarized by Hubbs and Lagler (1958:80) is from northern British Columbia and the southern parts of the Hudson Bay drainage of Canada east to Nova Scotia; southward through New England to the Patapsco and Potomac drainages of Maryland; it occurs in southern Ontario, southern Michigan, southeastern Wisconsin, Minnesota, the Dakotas, Montana, Colorado, and, as isolated glacial relict populations, in the Sand Hill region of Nebraska. The distribution of *C. eos* in western Canada is discontinuous (Scott, 1957:161).

Hubbs and Lagler (*loc. cit.*) listed *C. erythrogaster* from the Mississippi drainage of Iowa and southern Minnesota through southern Wisconsin to southeastern Michigan and to the Ohio River drainages of Pennsylvania and West Virginia; southward to the Tennessee River system in Tennessee and northern Alabama and to the northern part of the Ozark upland in Arkansas and Oklahoma, the Missouri River drainage in Kansas and an isolated area in the Arkansas River watershed of New Mexico. *C. erythrogaster* was reported from the state of Mississippi by Hemphill (1957:53).

C. erythrogaster has apparently not been previously reported north of Iowa in the Missouri River drainage system (Harlan and Speaker, 1956:89). Seven specimens collected in Kanaranzi Creek west of Adrian, Nobles County, on 2 October 1954 (University of Minnesota Coll. No. 18245), extend the known range of this species northward in the Missouri River drainage into Minnesota. These specimens were misidentified as C. eos by Underhill (1957: Map 7, page unnumbered).

C. neogaeus was listed by Hubbs and Lagler (loc. cit.) from the Northwest Territories of Canada through the southern drainage of Hudson Bay to New Brunswick, south to New England and the Adirondak region, and to southern Ontario, southern Michigan, southern Wisconsin, and northern Minnesota. Glacial relict populations are in the Black Hills of South Dakota.

Bailey and Allum considered C. neogaeus a glacial relict in the Missouri River basin. These authors included Colorado within its range on the basis of a hybrid between it and C. eos (1962:40).

C. oreas occurs in the James, Kanawha, New, and Roanoke River systems in the eastern United States (Miller, 1946:207).

Ecological Distribution.

C. eos and C. erythrogaster have been taken in lakes, rivers, and streams in Minnesota. Most collections are from streams.

C. erythrogaster is most abundant in Minnesota in spring-fed tributaries of such rivers as the Cannon, Cedar, and Zumbro of the lower Mississippi River drainage system. Similar habitats are seemingly preferred in other areas as well (see, for example, Cross, 1967:82; Metcalf, 1966:102; O'Donnell, 1935: 480; Trautman, 1957:328; Zahuranec, 1962:843). Trautman (*loc. cit.*) stated that the largest populations of *C. erythrogaster* in Ohio occurred in permanent brooks of clear water which were not often flooded, which flowed between wooded banks and contained long pools of moving water, and which had "cut banks" overhung by vegetation. To Trautman, these "cut banks" appeared to be important places of refuge.

C. eos may occur in a wider variety of habitats than *C. erythrogaster*. Hubbs and Cooper (1936:71) said:

> "The two species live in very different types of habitats: *eos* in bog ponds and lakes and sluggish mud-bottomed creeks; *erythrogaster* in clear, gravel-bottomed streams."

These authors also stated (p. 72) that *C. eos* seems to prefer acid or bog waters, although they also found it abundant in small ponds where there was a heavy growth of *Chara* and rapid deposition of marl. The occurrence of *C. eos* in boggy waters is also well-documented by other authors (Carl and Clemens, 1953:87; Livingstone, 1951:42; Ryder *et al*, 1964:13; Smith and Moyle, 1944:121).

C. eos was collected in and around Itasca Park, Clearwater County, Minnesota, in 1965. It was noted as most abundant in swift, clear streams, notably the headwaters of the Mississippi River and the Straight River 25 miles to the south. It was also common in certain lakes in the area. C. erythrogaster apparently rarely occurs in lakes.

In the Mississippi headwaters, C. eos abounded in a pool near the northern boundary of Itasca Park. The pool was 34 m long and 29 m wide at its maximum. Its maximum depth was 1.5 m. The current ranged in velocity from a maximum of 0.4 m per second near the center to zero near the shore. The substrate was composed of boulders, gravel, rubble, sand, silt, and combinations of these materials. The daytime water temperature averaged 20°C (in June). C. eos was most common in rapidly flowing water (current velocity 0.2 m per second) over sand and gravel bars near beds of emergent and floating vegetation. These beds included (nomenclature of Gleason and Cronquist, 1963): Family Alismataceae: Sagittaria sp.; Cyperaceae: Scirpus acutus, S. fluviatilis; Gramineae: Glyceria sp.; Hydrocharitaceae: Anacharis canadensis; Lemnaceae: Lemna minor, Spirodela polyrhiza; Nymphaeaceae: Cabomba caroliniana, Nymphaea tuberosa; Pontederiaceae: Zosterella dubia; and Typhaceae: Typha latifolia.

I do not know if the streams of southern Minnesota, which are probably generally warmer than those further north, favor *C. erythrogaster* over *C. eos* (or if the colder northern streams favor *C. eos*). I suspect that, if populations of *C. eos* exist in the lower Mississippi drainage in Minnesota, they would be found in the cool tributaries of the Root River in the southeastern part of the state.

The *C. erythrogaster* in the Zumbro River system apparently migrate from headwater streams toward the mainstream as winter approaches. None were captured in minnow traps placed in the headwaters in Dodge County in December, 1966, or in January and February, 1967. The latest date of the year on which this species was taken in this stream was 12 November 1966, when six specimens were seined. The movement of minnows from headwater areas to rivers was noted by Miller (1964:315).

The habits of *C. neogaeus* are poorly known. It apparently frequents streams having deep pools that are difficult to seine and, consequently, has not been collected extensively. Recent use of minnow traps in streams in and near Itasca Park by Mr. Richard Stasiak of the University of Minnesota indicates that this species is more common in this area than was formerly realized.

Distribution in Minnesota.

The drainage systems of Minnesota are formed by the waters of the Mississippi River system, which flow into the Gulf of Mexico, the streams of the Lake Superior region, which are ultimately drained by the Gulf of St. Lawrence, and the Red River and Arctic basins, which both drain into Hudson Bay.

The Mississippi drainage is here subdivided into five basins, following Underhill (1957:2): (1) the upper Mississippi basin, from the headwaters of the Mississippi at Lake Itasca to St. Anthony Falls in Minneapolis, (2) the lower Mississippi basin, south of St. Anthony Falls and including the Cedar and Des Moines River systems of southern Minnesota, (3) the St. Croix basin, from the headwaters of the St. Croix River to the Mississippi near Hastings, (4) the Minnesota basin, from Big Stone Lake to the Mississippi near Fort Snelling, and (5) the Missouri basin, consisting in Minnesota of small streams in the southwestern part of the state.

Chrosomus eos is known from the Arctic, Cedar, Minnesota, lower Mississippi, upper Mississippi, Red River, St. Croix, and Superior drainage basins in Minnesota. It has not been collected in the Des Moines or Missouri River basins. *C. erythrogaster* occurs in Minnesota in the Cedar, lower Mississippi, and Missouri basins (Table 2).

The lower Mississippi River is perhaps the source region for these species in Minnesota (Underhill, p. 24).

TABLE 2. Known distribution of *Chrosomus erythrogaster* and *C. eos* in Minnesota based on presence or absence in the drainage basins of the state.

	Distributional status of:	
Drainage	*C. erythrogaster*	*C. eos*
ARCTIC	Absent	Present
MISSISSIPPI		
Cedar River basin	Present	Present
Des Moines River basin	Absent, at least not yet collected	Absent, at least not yet collected
Minnesota River basin	Absent, at least not yet collected	Present
lower Mississippi River basin	Present	Present
upper Mississippi River basin	Absent	Present
Missouri River basin	Present	Absent, at least not yet collected
St. Croix River basin	Absent, at least not yet collected	Present
RED RIVER	Absent	Present
SUPERIOR	Absent	Present

If so, it appears that *C. eos* arrived around the time of the close of the final (Wisconsin) stage of the Pleistocene Epoch and dispersed via postglacial interconnections between drainage basins that are now separated (Underhill, p. 28). *C. erythrogaster* either arrived after present-day barriers to migration between drainage basins had been established in Minnesota, or was ecologically restricted to the lower Mississippi basin (Underhill, p. 29).

C. erythrogaster abounds in Minnesota in certain tributaries of the lower Mississippi, such as the Zumbro River. It is not known from the Minnesota or St. Croix basins, despite the connections existing between these river systems and the Mississippi. Its apparent ecological preference for smaller streams may limit its "drive" to swim through long stretches of the Mississippi and expand its range northward.

C. eos is common in the Arctic, upper Mississippi, Red River, and Superior drainage basins. Large collections of this species were taken in the Credit River and Nine Mile Creek in the Minnesota River basin in 1954 and 1955. Two collections from the Credit River made subsequent to 1955 are on record at the Zoology Building, University of Minnesota. Both were made in 1956 and neither included *C. eos*. I failed to take this species in three collecting trips to the Credit River in 1967.

C. eos is apparently rare (possibly even now absent) in the lower Mississippi basin, being represented from this basin in Minnesota in five collections available at the University of Minnesota:

Coll. No.	Date	Locality	No. specimens
14122	31 July 1940	Lake Pepin	1
18235	28 July 1952	north branch Zumbro River, Rice County	6
18248	14 May 1955	Cedar River, Mower County	1
19057	20 August 1943	South Branch Creek, Fillmore County	22
19058	2 August 1945	Fountain Lake Creek, Freeborn County	9

The apparent rarity of *C. eos* where *C. erythrogaster* occurs implies either a competitive advantage for *C. erythrogaster* or the existence of some environmental condition(s) that favor the latter species.

It seems unlikely that lack of temperature hardiness limits *C. eos* in the lower Mississippi basin, for it not only ranges far to the north where temperatures are generally lower, but has been experimentally shown to adapt to temperatures as high as 32°C (Brett, 1944:25). Recognizing that response to other factors related to the environment (e.g., oxygen availability, turbidity, substrate, noxious pollutants) may favor *C. erythrogaster* over *C. eos* in southern Minnesota, one can at present only speculate on what factors were operative.

Information on the relationships between C. eos and C. erythrogaster was not compiled in the present study, as populations with both occurring together were not found. However, comments by Greene (1935:122) indicate a possible competitive advantage for C. erythrogaster and provide information on its mode of dispersal as well:

> "The northern limit of this southern species in Wisconsin is reached in the northwestern corner of Clark County. Its range here overlaps that of the northern species (C. eos) to some extent, although usually the two have distinct ranges. In the area of overlap the two species are often found together; both prefer the small stream habitat. As is usual when a northern and southern form meet in Wisconsin, the northern species is the more common in the Lake Michigan basin, having apparently become established first through the use of the glacial lake outlets, while the more southern species has pushed up from the south at a later date.
>
> The occurrence of C. erythrogaster in the Lake Michigan drainage of Wisconsin may be explained by crossovers through the headwaters of the Des Plaines, Fox, and Rock rivers. The west to east dispersal of this species into the Lake Michigan drainage is strongly suggested by reversal of the usual comparative positions of the two species in the Milwaukee and Pike rivers. Usually where both species are present in one river system, as in the Chippewa and Wisconsin rivers, C. erythrogaster is in the lower waters, C. eos in the upper, the natural sequence of southern and northern forms. In the Milwaukee and Pike rivers, however, C. erythrogaster is in the upper waters and the single records of C. eos in each system are near the mouths of the rivers. This suggests that C. eos has been displaced in the upper waters after the entrance of C. erythrogaster through the headwaters."

An alternative hypothesis is that *C. eos* has replaced *C. erythrogaster* at the mouths of these streams. My findings are not in agreement with Greene's statement that the two species are "often found together" where they are sympatric. Is the discrepency between our findings one of specimen misidentification, or do geographical and ecological habitat differences exist between southern Minnesota and the areas in Wisconsin mentioned by Greene? As mentioned previously, records of *C. eos* are known where *C. erythrogaster* occurs in southern Minnesota. Indications are that *C. eos* is perhaps near extirpation there.

The distributional patterns of *C. eos* and *C. erythrogaster* in Minnesota and the close resemblance they have to each other have caused difficulties in interpreting their taxonomic relationships. Underhill (1957) examined specimens from east-central Minnesota that were referable to *C. eos* or *C. erythrogaster* but he could not ascertain which: "The possibility of intergrades between the northern and southern redbelly dace is suspected, particularly in those specimens from the Credit, Cannon, and Zumbro Rivers (p. 13)".

The possible existence of morphologically intermediate populations in an area geographically intermediate between *C. eos* to the north and *C.*

erythrogaster to the south (i.e., clinal variation) was thereby suggested (cf. Hubbs, 1943:114). However, Underhill plotted a distribution map (Map 7, page unnumbered) in which *C. eos* and *C. erythrogaster* were treated as separate species and collections from 12 localities on the Cannon, Credit, Zumbro, and (?) Vermillion Rivers were shown as hybrids between them.

The localities from which these "hybrids" came were determined by examining Underhill's Map 7. These localities were interpreted as follows:

(Minnesota River basin)

(1) Credit River, near Savage, Scott County. The single locality shown on Underhill's map probably refers to four collections taken near each other in this river above Savage:

Coll. No.	Date	No. specimens
18233	15 May 1954	35
18237	16 April 1955	5
18238	16 April 1955	10
18244	19 June 1954	19

I identified the specimens in these four collections as *C. eos*.

(Lower Mississippi River basin)

(2) Apparently from the Vermillion River or tributary thereof, near Hastings. This collection was not located in the University of Minnesota collection.

It should be noted that Underhill examined some collections at the Minnesota Conservation Department. I did not examine these.

(3) Cannon River or tributary thereof, near Welch, Goodhue County. This collection was not located in the present study.

(4) Prairie Dog Creek, (?) Rice County. This collection was not located in the present study.

(5) Middle branch of the Zumbro River, (?) Olmsted County. This collection was not located in the present study.

(6) Little Cannon River, Cannon Falls, Goodhue County (two collections).

18176	29 May 1954	4
18240	29 May 1954	1

I identified the specimens in these two collections as C. erythrogaster.

(7) North branch of the Zumbro River, Rice County. The single locality indicated on Underhill's map probably refers to three collections taken close to each other:

18177 (T109N-R19W-S11/12)	13 June 1953	2
18235 (T109N-R19W-S12)	28 July 1952	20
18236 (T109-R19W-S9)	28 July 1952	17

I identified the specimens in Collections 18177 and 18236 as C. erythrogaster. Collection 18235 contained six *C. eos* and 14 *C. erythrogaster*.

(8) North branch of the Zumbro River, Goodhue County, T110N-R17W-S32/33.

18239	13 June 1953	1

I identified this specimen as *C. erythrogaster*.

(9) North branch of the Zumbro River, Wanamingo, Goodhue County.

18242	31 May 1954	1

I identified this specimen as *C. erythrogaster*.

(10) Belle Creek, Goodhue County.

18243	8 August 1954	2

I identified these specimens as *C. erythrogaster*.

(11) South branch of the Zumbro River, Dodge County.

18247	24 June 1954	1

I identified this specimen as *C. erythrogaster*.

(12) North branch of the Zumbro River, Goodhue County, T110N-R18W-S25.

18870	7 May 1955	115

I identified these specimens as *C. erythrogaster*.

C. erythrogaster was excluded from the Minnesota River drainage on the basis of the identifications made here of the specimens from Credit River and Nine Mile Creek. Except for the *C. eos* in Collection 18235, all other "hybrids" shown on Underhill's map were identified as *C. erythrogaster*. The "intergradation" noted by Underhill can perhaps be relegated equally well to individual and ontogenetic variation, especially since many of the problematical specimens were small and therefore relatively difficult to identify.

There is no evidence that these species hybridize in Minnesota. Of the 1,314 specimens from the Arctic, Minnesota, upper Mississippi, Red River, and Superior drainage basins examined in this study, not one qualified as C. erythrogaster based on the criteria used here. The close similarity in morphology and meristic characters between the two species supports the view that they are closely related.

VARIATION

Reliability of Measurements.

It is advisable to test the reliability of measurements and meristic counts used in a taxonomic study employing morphological characters, and to determine if the investigator inadvertently varies his methods of measuring and counting in the course of the investigation (Kim *et al*, 1966:28; Underhill and Merrell, 1959:134).

The reliability of measurements and meristic counts in the present study was tested in a manner similar to the method of Kim *et al* (p. 26) in which the same characters are measured or counted on the same specimen on three different occasions. The coefficient of variation for each character is then determined.

In the present study, 12 specimens were used to test the reliability of counts and measurements -- three "large" *C. erythrogaster*, three "small" *C. erythrogaster*, three "large" *C. eos*, and three "small" *C. eos*. For each specimen, 20 characters (seven meristic counts and 13 measurements) were tallied. Coefficients of variation derived from these counts and measurements thus totaled 240 (12 specimens x 20 characters per specimen = 240).

The measurements and counts appear to be reliable. 216 of the 240 coefficients of variation were less than 5 percent and only one exceeded 10 percent (Table 3). Coefficients of variation were relatively greater in "small" specimens of both species than in "large" ones. Absolute errors could increase when smaller specimens are used because these specimens are harder to handle than large ones and because some structures (as fin rays) are not yet fully developed and are therefore more difficult to count. However, even if the errors made on small specimens were no greater in absolute magnitude than those made on larger animals, the coefficients of variation for smaller fishes would obviously increase because the percentage error is larger.

TABLE 3 (A-D). Reliability of measurements and meristic counts of taxonomic characters made on randomly-selected specimens of *Chrosomus erythrogaster* and *C. eos*. Each character was measured or counted on three separate occasions, the dates of which are given in the Table.

A_1-A_3 -- "Large" *C. erythrogaster*. From Otter Creek at County Road 6, Mower County, Minnesota, 24 October 1964.

B_1-B_3 -- "Small" *C. erythrogaster*. (Same locality and date).

C_1-C_3 -- "Large" *C. eos*. From Mississippi River headwaters, Itasca Park, Clearwater County, Minnesota, 22 June 1964.

D_1-D_3 -- "Small" *C. eos*. From Cascade River, Cook County, Minnesota, 6 August 1941.

Measurements are in millimeters. Figures representing Means and Coefficients of Variation are rounded off for tabular presentation.

TABLE $3A_1$ ("large" C. erythrogaster, specimen 1).

Character	1*	2*	3*	$\overline{X}$	S.D.	C.V. %
Total length	67.4	68.4	67.8	67.9	.51	0.7
Standard l.	53.5	55.5	55.3	54.8	1.10	2.0
Orbit length	3.2	3.3	3.3	3.3	.07	2.2
Snout length	3.6	3.6	3.5	3.6	.07	2.0
Postorbit l.	5.7	5.8	5.8	5.8	.07	1.2
Head length	12.6	12.8	12.9	12.8	.16	1.2
Head depth	8.2	8.2	8.1	8.2	.07	0.9
Lateral scale rows	85	90	90	88.3	2.89	3.3
Scale rows on caudal pd'cle	25	24	25	24.7	.58	2.3
Dorsal rays	8	8	8	8	.00	0.0
Anal rays	8	8	8	8	.00	0.0
Caudal rays	19	19	19	19	.00	0.0
Pectoral rays	14	16	16	15.3	1.16	7.5
Pelvic rays	8	8	8	8	.00	0.0
Mouth length	3.2	3.1	3.2	3.2	.07	2.2
Mouth angle	50^{o}	52	53	51.7	1.53	3.0
Pct'ral fin l.	9.1	9.2	9.4	9.2	.16	1.7
Pelvic fin l.	7.6	7.8	7.9	7.8	.16	2.0
Depressed dorsal fin l.	11.6	11.3	11.8	11.6	.26	2.2
Anal fin l.	10.8	11.0	10.4	10.7	.31	2.9

*(1) 27 Jan 1965 (2) 16 Dec 1966 (3) 7 Feb 1967.

TABLE 3A_2 ("large" C. erythrogaster, specimen 2).

Character	1*	2*	3*	$\overline{X}$	S.D.	C.V. %
Total length	62.6	61.6	62.1	62.1	.50	0.8
Standard l.	50.1	50.8	50.6	50.5	.36	0.7
Orbit length	3.2	3.3	3.2	3.2	.07	2.2
Snout length	4.0	3.9	3.9	3.9	.07	2.0
Postorbit l.	6.4	6.3	6.3	6.3	.07	1.1
Head length	13.4	13.3	13.3	13.3	.07	0.5
Head depth	8.4	8.7	8.4	8.5	.17	2.0
Lateral scale rows	87	87	87	87	.00	0.0
Scale rows on caudal pd'cle	26	24	23	24.3	1.53	6.3
Dorsal rays	8	8	8	8	.00	0.0
Anal rays	8	8	8	8	.00	0.0
Caudal rays	19	19	19	19	.00	0.0
Pectoral rays	16	17	17	16.7	.58	3.5
Pelvic rays	8	8	8	8	.00	0.0
Mouth length	3.1	2.9	3.1	3.0	.12	4.0
Mouth angle	50°	49	52	50.3	1.58	3.1
Pct'ral fin l.	10.4	10.4	10.4	10.4	.00	0.0
Pelvic fin l.	8.5	8.6	8.3	8.5	.16	1.9
Depressed dorsal fin l.	10.5	10.6	10.9	10.7	.21	2.0
Anal fin l.	9.5	9.8	9.4	9.6	.21	2.2

*(1) 31 Jan 1965 (2) 16 Dec 1966 (3) 7 Feb 1967.

TABLE $3A_3$ ("large" <u>C.</u> <u>erythrogaster</u>, specimen 3).

Character	1*	2*	3*	$\overline{X}$	S.D.	C.V. %
Total length	68.6	68.0	67.7	68.1	.46	0.7
Standard l.	54.9	55.2	55.8	55.3	.46	0.8
Orbit length	3.4	3.4	3.4	3.4	.00	0.0
Snout length	3.8	3.8	3.8	3.8	.00	0.0
Postorbit l.	6.2	6.2	6.3	6.2	.07	1.1
Head length	13.2	13.3	13.2	13.2	.07	0.5
Head depth	8.8	8.5	8.2	8.5	.30	3.5
Lateral scale rows	82	87	91	86.7	4.51	5.2
Scale rows on caudal pd'cle	22	22	22	22	.00	0.0
Dorsal rays	8	8	8	8	.00	0.0
Anal rays	8	8	8	8	.00	0.0
Caudal rays	19	19	19	19	.00	0.0
Pectoral rays	14	14	14	14	.00	0.0
Pelvic rays	8	8	8	8	.00	0.0
Mouth length	3.1	3.0	2.8	3.0	.16	5.3
Mouth angle	48^{o}	47	49	48	1.00	2.1
Pct'ral fin l.	9.3	9.5	9.4	9.4	.10	1.1
Pelvic fin l.	7.8	7.7	7.8	7.8	.07	0.9
Depressed dorsal fin l.	11.5	11.5	11.2	11.4	.17	1.5
Anal fin l.	10.5	10.5	10.5	10.5	.00	0.0

*(1) 11 Feb 1965 (2) 16 Dec 1966 (3) 7 Feb 1967.

TABLE $3B_1$ ("small" <u>C. erythrogaster</u>, specimen 1).

Character	1*	2*	3*	$\bar{X}$	S.D.	C.V. %
Total length	34.3	33.3	34.1	33.9	.53	1.6
Standard l.	28.0	27.4	28.3	27.9	.46	1.6
Orbit length	2.3	2.2	2.3	2.3	.07	3.1
Snout length	1.7	1.7	1.8	1.7	.07	4.1
Postorbit l.	3.2	3.2	3.2	3.2	.00	0.0
Head length	7.1	7.3	7.2	7.2	.10	1.4
Head depth	4.8	4.7	4.6	4.7	.10	2.1
Lateral scale rows	81	78	77	79	2.08	2.7
Scale rows on caudal pd'cle	22	23	25	23	1.53	6.6
Dorsal rays	8	8	8	8	.00	0.0
Anal rays	8	8	8	8	.00	0.0
Caudal rays	18	18	18	18	.00	0.0
Pectoral rays	14	14	13	14	.57	4.2
Pelvic rays	8	8	8	8	.00	0.0
Mouth length	1.6	1.6	1.7	1.6	.07	4.4
Mouth angle	51°	53	54	53	1.53	2.9
Pct'ral fin l.	5.1	5.0	5.4	5.2	.21	4.1
Pelvic fin l.	4.6	4.4	4.2	4.4	.20	4.6
Depressed dorsal fin l.	6.7	6.6	6.4	6.6	.16	2.4
Anal fin l.	5.5	5.4	5.0	5.3	.27	5.0

*(1) 23 Feb 1965 (2) 16 Dec 1966 (3) 7 Feb 1967.

TABLE $3B_2$ ("small" C. erythrogaster, specimen 2).

Character	1*	2*	3*	$\overline{X}$	S.D.	C.V. %
Total length	34.3	34.0	33.7	34.0	.30	0.9
Standard l.	27.5	27.1	26.9	27.2	.31	1.1
Orbit length	2.0	2.0	2.1	2.0	.07	3.5
Snout length	1.5	1.7	1.6	1.6	.10	6.3
Postorbit l.	3.1	3.1	3.1	3.1	.00	0.0
Head length	6.7	6.7	6.8	6.7	.07	1.1
Head depth	4.5	4.3	4.4	4.4	.10	2.3
Lateral scale rows	83	79	78	80	2.64	3.3
Scale rows on caudal pd'cle	21	20	24	22	2.08	9.6
Dorsal rays	8	8	8	8	.00	0.0
Anal rays	8	8	8	8	.00	0.0
Caudal rays	19	19	19	19	.00	0.0
Pectoral rays	13	13	14	13	.53	4.3
Pelvic rays	8	8	8	8	.00	0.0
Mouth length	1.7	1.8	1.8	1.7	.07	4.1
Mouth angle	51°	54	55	53	2.08	3.9
Pct'ral fin l.	4.7	4.9	4.5	4.7	.20	4.3
Pelvic fin l.	3.9	3.6	3.6	3.7	.17	4.7
Depressed dorsal fin l.	5.7	5.9	5.7	5.8	.12	2.1
Anal fin l.	5.3	5.2	4.9	5.1	.21	4.1

*(1) 24 Feb 1965 (2) 16 Dec 1966 (3) 7 Feb 1967.

TABLE $3B_3$ ("small" C. erythrogaster, specimen 3).

Character	1*	2*	3*	$\overline{X}$	S.D.	C.V. %
Total length	31.7	30.6	30.5	30.9	.67	2.2
Standard l.	23.7	22.9	23.6	23.4	.44	1.9
Orbit length	2.1	2.0	2.0	2.0	.07	3.5
Snout length	1.5	1.6	1.5	1.5	.07	4.6
Postorbit l.	2.9	2.8	2.8	2.8	.07	2.5
Head length	6.3	6.3	6.3	6.3	.00	0.0
Head depth	4.2	4.2	4.1	4.2	.07	1.7
Lateral scale rows	80	82	83	82	1.58	1.9
Scale rows on caudal pd'cle	22	23	22	22	.58	2.6
Dorsal rays	7	8	8	8	.55	7.2
Anal rays	8	8	8	8	.00	0.0
Caudal rays	19	19	19	19	.00	0.0
Pectoral rays	13	15	14	14	1.00	0.7
Pelvic rays	8	8	8	8	.00	0.0
Mouth length	1.5	1.5	1.4	1.5	.07	4.8
Mouth angle	51°	53	52	52	1.00	1.9
Pct'ral fin l.	4.2	4.4	4.0	4.2	.20	4.8
Pelvic fin l.	3.5	3.4	3.2	3.4	.16	4.7
Depressed dorsal fin l.	6.2	6.0	5.3	5.8	.47	8.1
Anal fin l.	5.0	5.2	4.5	4.9	.36	7.4

*(1) 24 Feb 1965 (2) 16 Dec 1966 (3) 7 Feb 1967.

TABLE $3C_1$ ("large" C. eos, specimen 1).

Character	1*	2*	3*	$\bar{X}$	S.D.	C.V. %
Total length	55.0	54.7	54.5	54.7	.26	0.5
Standard l.	44.6	43.8	43.5	44.0	.57	1.3
Orbit length	3.1	3.1	3.1	3.1	.00	0.0
Snout length	2.9	2.9	2.9	2.9	.00	0.0
Postorbit l.	5.8	5.8	5.8	5.8	.00	0.0
Head length	11.9	11.8	11.8	11.8	.07	0.6
Head depth	7.8	7.9	7.6	7.8	.16	2.0
Lateral scale rows	85	82	81	83	2.08	2.5
Scale rows on caudal pd'cle	22	22	24	23	1.16	5.1
Dorsal rays	8	8	8	8	.00	0.0
Anal rays	8	8	8	8	.00	0.0
Caudal rays	18	18	18	18	.00	0.0
Pectoral rays	17	18	17	17	.58	3.3
Pelvic rays	8	8	8	8	.00	0.0
Mouth length	2.9	2.8	3.0	2.9	.10	3.5
Mouth angle	64°	63	60	62	2.08	3.3
Pct'ral fin l.	9.0	9.4	9.0	9.1	.24	2.6
Pelvic fin l.	7.5	7.1	6.8	7.1	.35	5.0
Depressed dorsal fin l.	9.0	9.1	9.3	9.1	.16	1.7
Anal fin l.	8.1	8.1	8.1	8.1	.00	0.0

*(1) 16 Aug 1965 (2) 16 Dec 1966 (3) 7 Feb 1967.

TABLE $3C_2$ ("large" C. eos, specimen 2).

Character	1*	2*	3*	$\bar{X}$	S.D.	C.V. %
Total length	62.5	62.0	61.2	61.9	.66	1.1
Standard l.	50.7	50.2	49.5	50.1	.61	1.2
Orbit length	3.2	3.2	3.2	3.2	.00	0.0
Snout length	3.2	3.3	3.3	3.3	.07	2.2
Postorbit l.	6.1	6.0	6.2	6.1	.10	1.6
Head length	12.4	12.5	12.3	12.4	.10	0.8
Head depth	7.7	7.7	7.7	7.7	.00	0.0
Lateral scale rows	93	94	86	91	4.36	4.8
Scale rows on caudal pd'cle	22	24	23	23	1.00	4.4
Dorsal rays	8	8	8	8	.00	0.0
Anal rays	8	8	8	8	.00	0.0
Caudal rays	19	19	19	19	.00	0.0
Pectoral rays	17	17	18	17	.58	3.3
Pelvic rays	9	9	9	9	.00	0.0
Mouth length	2.8	2.8	2.7	2.8	.07	2.6
Mouth angle	58°	61	60	60	1.53	2.6
Pct'ral fin l.	8.3	8.5	8.4	8.4	.10	1.2
Pelvic fin l.	6.7	6.5	6.4	6.5	.16	2.4
Depressed dorsal fin l.	9.5	9.8	9.3	9.5	.26	2.7
Anal fin l.	8.2	8.1	8.6	8.3	.27	3.2

*(1) 22 Aug 1965 (2) 16 Dec 1966 (3) 7 Feb 1967.

TABLE $3C_3$ ("large" C. eos, specimen 3).

Character	1*	2*	3*	$\overline{X}$	S.D.	C.V. %
Total length	55.4	54.3	55.2	55.0	.59	1.1
Standard l.	44.7	43.3	44.2	44.1	.71	1.6
Orbit length	3.1	3.1	3.1	3.1	.00	0.0
Snout length	3.1	3.1	3.0	3.1	.07	2.3
Postorbit l.	5.5	5.5	5.3	5.4	.12	2.3
Head length	11.5	11.5	11.3	11.4	.12	1.1
Head depth	7.7	7.6	7.4	7.6	.16	2.1
Lateral scale rows	85	83	81	82	2.00	2.4
Scale rows on caudal pd'cle	22	23	24	23	1.00	4.4
Dorsal rays	8	8	8	8	.00	0.0
Anal rays	8	8	8	8	.00	0.0
Caudal rays	19	19	19	19	.00	0.0
Pectoral rays	16	16	16	16	.00	0.0
Pelvic rays	8	8	8	8	.00	0.0
Mouth length	2.8	2.7	2.7	2.7	.07	2.6
Mouth angle	61°	59	57	59	2.00	3.4
Pct'ral fin l.	9.6	9.3	9.2	9.4	.21	2.3
Pelvic fin l.	6.6	6.4	6.7	6.6	.16	2.3
Depressed dorsal fin l.	8.9	9.0	9.3	9.1	.21	2.3
Anal fin l.	8.4	8.3	8.0	8.2	.21	2.6

*(1) 13 Sept 1965 (2) 16 Dec 1966 (3) 7 Feb 1967.

TABLE $3D_1$ ("small" C. eos, specimen 1).

Character	1*	2*	3*	$\overline{X}$	S.D.	C.V. %
Total length	29.3	29.5	29.7	29.5	.20	0.7
Standard l.	23.1	22.5	23.3	23.0	.42	1.8
Orbit length	2.0	2.0	2.1	2.0	.07	3.5
Snout length	1.6	1.4	1.5	1.5	.10	6.7
Postorbit l.	3.1	2.8	3.0	3.0	.16	5.3
Head length	6.5	6.8	6.7	6.7	.16	2.4
Head depth	4.7	4.6	4.5	4.6	.10	2.2
Lateral scale rows	78	81	86	82	4.04	5.0
Scale rows on caudal pd'cle	23	24	26	24	1.53	6.3
Dorsal rays	8	8	8	8	.00	0.0
Anal rays	8	8	8	8	.00	0.0
Caudal rays	19	19	19	19	.00	0.0
Pectoral rays	15	14	16	15	1.00	6.7
Pelvic rays	8	8	8	8	.00	0.0
Mouth length	1.6	1.3	1.5	1.5	.16	10.8
Mouth angle	55°	56	52	54	2.08	3.8
Pct'ral fin l.	4.3	4.5	4.5	4.4	.12	2.6
Pelvic fin l.	2.8	2.8	2.8	2.8	.00	0.0
Depressed dorsal fin l.	4.6	4.8	4.9	4.8	.16	3.3
Anal fin l.	4.0	4.1	4.2	4.1	.10	2.4

*(1) 6 Dec 1966 (2) 16 Dec 1966 (3) 7 Feb 1967.

TABLE $3D_2$ ("small" C. eos, specimen 2).

Character	1*	2*	3*	$\overline{X}$	S.D.	C.V. %
Total length	29.3	29.2	29.0	29.2	.16	0.5
Standard l.	23.0	22.9	22.5	22.8	.27	1.2
Orbit length	2.1	1.9	2.0	2.0	.10	5.0
Snout length	1.6	1.5	1.5	1.5	.07	4.6
Postorbit l.	3.0	2.9	2.8	2.9	.10	3.5
Head length	6.5	6.4	6.3	6.4	.10	1.6
Head depth	4.2	4.6	4.5	4.4	.21	4.8
Lateral scale rows	83	77	85	82	4.16	5.1
Scale rows on caudal pd'cle	22	21	23	22	1.00	4.6
Dorsal rays	8	8	8	8	.00	0.0
Anal rays	8	8	8	8	.00	0.0
Caudal rays	19	19	19	19	.00	0.0
Pectoral rays	13	13	13	13	.00	0.0
Pelvic rays	8	8	8	8	.00	0.0
Mouth length	1.5	1.6	1.5	1.5	.07	4.6
Mouth angle	55^{o}	54	58	56	2.08	3.7
Pct'ral fin l.	3.8	3.8	3.8	3.8	.00	0.0
Pelvic fin l.	2.9	2.9	3.1	3.0	.12	4.1
Depressed dorsal fin l.	4.3	4.3	4.2	4.3	.07	1.7
Anal fin l.	4.1	4.0	3.9	4.0	.10	2.5

*(1) 6 Dec 1966 (2) 16 Dec 1966 (3) 7 Feb 1967.

TABLE $3D_3$ ("small" C. eos, specimen 3).

Character	1*	2*	3*	$\overline{X}$	S.D.	C.V. %
Total length	29.2	28.8	29.6	29.2	.40	1.4
Standard l.	23.0	23.3	23.7	23.3	.35	1.5
Orbit length	2.1	2.2	2.2	2.2	.07	3.3
Snout length	1.5	1.6	1.5	1.5	.07	4.6
Postorbit l.	3.2	3.2	3.2	3.2	.00	0.0
Head length	6.9	6.8	6.7	6.8	.10	1.5
Head depth	4.4	4.4	4.4	4.4	.00	0.0
Lateral scale rows	80	82	85	82	2.52	3.1
Scale rows on caudal pd'cle	20	22	23	22	1.53	7.1
Dorsal rays	8	8	8	8	.00	0.0
Anal rays	7	8	7	7	.58	7.9
Caudal rays	19	19	19	19	.00	0.0
Pectoral rays	13	14	15	14	1.00	0.7
Pelvic rays	8	8	8	8	.00	0.0
Mouth length	1.4	1.6	1.6	1.5	.12	8.0
Mouth angle	56°	57	58	57	1.00	1.8
Pct'ral fin l.	4.5	4.5	4.5	4.5	.00	0.0
Pelvic fin l.	2.8	3.0	3.0	2.9	.12	4.2
Depressed dorsal fin l.	4.9	4.8	4.8	4.8	.07	1.5
Anal fin l.	4.4	4.5	4.5	4.5	.07	1.6

*(1) 6 Dec 1966 (2) 16 Dec 1966 (3) 7 Feb 1967.

Sexual Variation.

Statistical analyses were made to determine which of 20 external characters varied significantly between sexes in *C. erythrogaster* and *C. eos*. The samples tested each consisted of 30 males and 30 females. The *C. erythrogaster* were collected from Otter Creek at County Road 6, Mower County, Minnesota on 24 October 1964. The *C. eos* were taken in the Mississippi River headwaters, Itasca Park, Clearwater County, on 22 June 1964.

The characters exhibiting sexual dimorphism based on the "*t* tests" used for analysis were all measurements of fins or counts of fin rays. Pectoral and pelvic fins were significantly larger in males of both species. Dorsal and anal fins were significantly larger in males of *C. eos* but did not vary significantly between sexes in the *C. erythrogaster* studied. The number of rays in pectoral fins was significantly greater in males of the *C. erythrogaster* tested but not in *C. eos* (Table 4). Sexual dimorphism in size of fins of minnows is well-documented (Langlois, 1929:161; Murphy, 1943: 187; Phillips, 1967:11; Raney, 1940:399; Schwartz, 1958:143; Smith, 1908:11).

Sexually dimorphic characters were not included among the characters used in deriving the intercharacter correlation coefficients that were instrumental in

TABLE 4. Sexual variation in 20 morphological characters of *Chrosomus erythrogaster* and *C. eos*.

A. *C. erythrogaster*. Determined from a sample of 30 specimens of each sex taken from Otter Creek at County Road 6, Mower County, Minnesota, 24 October 1964.

B. *C. eos*. Determined from a sample of 30 specimens of each sex, taken from the Mississippi River headwaters, Itasca Park, Clearwater County, Minnesota, 22 June 1964.

Measurements are in millimeters.

TABLE 4A. (<u>C.</u> <u>erythrogaster</u>).

Character		Mean	Range	S.D.	$SE_{\bar{x}}$	<u>t</u>
Total length	♂	55.1	50.0-59.3	2.77	.51	0.026
	♀	55.1	50.6-59.0	2.18	.40	
Standard length		44.3	40.3-48.2	2.42	.44	0.053
		44.3	40.3-47.7	1.97	.36	
Orbit length		2.9	2.7- 3.2	.12	.02	0.333
		2.9	2.7- 3.1	.11	.02	
Snout length		3.0	2.5- 3.6	.23	.04	0.529
		3.0	2.5- 3.3	.20	.04	
Postorbit length		5.1	4.5- 5.9	.35	.06	0.513
		5.1	4.7- 5.7	.18	.03	
Head length		11.1	10.0-12.0	.56	.10	0.282
		11.1	10.4-11.9	.44	.08	
Head depth		7.2	6.4- 7.8	.36	.07	1.069
		7.1	6.5- 8.0	.34	.06	
Lateral scale rows		84.6	80 - 88	2.30	.42	0.830
		84.1	77 - 87	2.37	.43	
Scale rows on caudal peduncle		23.2	20 - 26	1.45	.26	0.651
		23.0	20 - 26	1.71	.31	
Number of dorsal rays		8.0	-	0.00	.00	1.000
		8.0	8 - 9	.19	.03	
Number of anal rays		7.9	7 - 8	.26	.05	0.000
		7.9	7 - 8	.26	.05	
Number of caudal rays		19.0	18 - 20	.32	.06	0.373
		19.0	18 - 20	.37	.07	
Number of pectoral rays		14.9	13 - 16	.77	.14	3.297**
		14.2	13 - 15	.72	.13	
Number of pelvic rays		8.0	8 - 9	.19	.03	0.000
		8.0	8 - 9	.19	.03	
Length of mouth		2.7	2.1- 3.1	.20	.03	1.111
		2.6	2.3- 2.9	.15	.03	

(TABLE 4A continued on next page).

TABLE 4A, Continued. (*C. erythrogaster*).

Character		Mean	Range	S.D.	$SE_{\bar{x}}$	t
Angle of	♂	50.9°	46 - 55	2.07	.38	1.483
mouth	♀	50.1	45 - 54	2.10	.38	
Length of		8.6	7.4- 9.3	.54	.10	6.817**
pectoral fins		7.8	7.2- 8.5	.33	.06	
Length of		6.8	5.9- 7.4	.47	.09	3.608**
pelvic fins		6.5	5.8- 6.8	.25	.05	
Length of		9.6	8.3-10.7	.67	.12	1.273
depressed		9.4	8.6-10.6	.41	.08	
dorsal fin						
Length of		8.4	7.3- 9.3	.55	.10	0.569
anal fin		8.5	7.9- 9.1	.39	.07	

**Highly significant ($P < 0.01$).

TABLE 4B. (C. eos).

Character		Mean	Range	S.D.	$SE_{\bar{x}}$	t
Total length	♂	53.8	50.4-57.1	1.69	.31	0.008
	♀	53.8	50.1-56.6	1.69	.31	
Standard length		43.7	40.6-46.5	1.44	.26	1.064
		44.1	41.0-46.4	1.50	.27	
Orbit length		3.0	2.7- 3.2	.13	.02	0.223
		3.0	2.8- 3.2	.10	.02	
Snout length		2.8	2.6- 3.2	.15	.03	0.356
		2.8	2.5- 3.0	.14	.03	
Postorbit length		5.7	5.0- 6.3	.31	.06	0.391
		5.7	5.0- 6.2	.28	.05	
Head length		11.5	10.5-12.4	.44	.08	0.120
		11.4	10.5-12.2	.42	.08	
Head depth		7.6	7.1- 8.2	.29	.05	0.906
		7.4	6.6- 7.8	.32	.06	
Lateral scale rows		84.4	80 - 88	2.08	.38	0.000
		84.4	78 - 88	1.99	.36	
Scale rows on caudal peduncle		23.6	22 - 27	1.30	.24	1.442
		23.2	20 - 25	1.20	.22	
Number of dorsal rays		8.0	-	0.00	.00	0.000
		8.0	-	0.00	.00	
Number of anal rays		8.0	-	0.00	.00	1.419
		7.9	7 - 8	.25	.05	
Number of caudal rays		18.9	18 - 19	.26	.05	1.203
		18.8	18 - 19	.37	.07	
Number of pectoral rays		15.9	14 - 18	1.00	.18	0.417
		15.8	14 - 17	.85	.16	
Number of pelvic rays		8.1	8 - 9	.26	.05	0.573
		8.1	8 - 9	.19	.03	
Length of mouth		2.6	2.4- 3.0	.15	.03	0.415
		2.6	2.2- 2.9	.17	.03	

(TABLE 4B continued on next page).

TABLE 4B, Continued. (*C. eos*).

Character		Mean	Range	S.D.	$SE_{\bar{x}}$	*t*
Angle of mouth	♂	60.1°	55 - 66	2.52	.46	0.463
	♀	60.0	55 - 65	2.50	.46	
Length of pectoral fins		8.9	8.0- 9.9	.51	.09	13.851**
		7.2	6.4- 8.0	.14	.08	
Length of pelvic fins		6.4	6.0- 7.2	.11	.06	7.649**
		5.8	5.1- 6.3	.11	.07	
Length of depressed dorsal fin		8.8	8.0- 9.8	.47	.09	5.126**
		8.2	7.3- 9.0	.45	.08	
Length of anal fin		7.7	7.0- 8.4	.39	.07	4.945**
		7.3	6.6- 8.0	.35	.07	

**Highly significant ($P < 0.01$).

analyzing morphological differences between the two species. In a sample designed to analyze interspecific morphological differences, the sexes would best be equally represented in all size ranges and from all localities if sexually dimorphic characters were included. This was not possible with the material available unless the sample size were reduced. It was also desired to emphasize characters useful for distinguishing between specimens of either species regardless of sex. It was therefore decided to eliminate characters showing sexual dimorphism, erect a sample of maximum geographic and size-class variation without regard to sex, and rely upon characters that do not vary with sex for evaluating the morphological differences between C. erythrogaster and C. eos.

Fin size was not used in analyzing morphological differences between the two species for the above reasons. However, the interspecific and ontogenetic variations noted in fin size merit discussion because they are interesting and may be of potential use for distinguishing between the two species.

An examination of the variations in fin size among specimens used in the study of sexual dimorphism and in other specimens examined in a similar manner revealed that:

(1) Although pectoral and pelvic fins were

significantly larger in males of both species, this difference was roughly twice as large in C. eos in the sample tested. "t" values for differences between sexes in size of these fins were (from Table 4):

	C. erythrogaster	C. eos
Pectoral fins	6.82**	13.85**
Pelvic fins	3.61**	7.65**

(** -- Highly significant. $P < 0.01$).

(2) Dorsal and anal fins were found to be significantly larger in males of C. eos but not in males of C. erythrogaster. Because these fins were sexually dimorphic in one species but not in the other, it was suspected that errors in measurement were responsible. However, re-examination of dorsal and anal fins in the same specimens validated the original findings. "t" values for differences between sexes in size of these fins were (from Table 4):

	C. erythrogaster	C. eos
Dorsal fin	1.27	5.13**
Anal fin	0.57	4.95**

(** -- Highly significant. $P < 0.01$).

The same results were obtained in larger specimens of C. eos (10 males and 10 females averaging 62.6 mm in total length) from the Credit River, Scott County, in the Minnesota River system.

(3) Sexual dimorphism in fin size is not apparent

in members of either species until a total length of 30-40 mm is attained, and this dimorphism becomes more pronounced as the fish grows.

Variations in fin size of *C. erythrogaster* and *C. eos* thus seem complex, with sexual dimorphism interwoven with ontogenetic and interspecific variations. Individual ("random") variation was, of course, noted, and sampling error could have influenced the findings.

It is also possible that geographical variation in fin size exists. Variation of this type could occur as a "cline" or haphazardly among different populations of the same species that are isolated from each other. Murphy (*loc. cit.*) suggested that sexual dimorphism in dorsal and anal fins occurs in minnows of the Genus *Rhinichthys* throughout their range.

It was beyond the scope of this study to analyze all the possible causes of variation listed above in size of fins in the redbelly dace studied. However, indications are that if one understood how the kinds of variation interact, fin size could be useful in distinguishing *C. erythrogaster* from *C. eos*.

Ontogenetic Variation.

An index of the relationships of various body dimensions to each other during ontogeny in *C. eos* and *C. erythrogaster* is provided by the correlation coefficients derived for the study of interspecific variation (Tables 5 and 6).

Total length, standard length, orbit length, snout length, postorbital length, head length, head depth, and length of mouth were all positively and highly correlated to each other in both species. The correlation coefficients of all pair combinations were always above 0.9 in the samples tested, indicating that all of these characters increase in size together with increased total length.

The "angle of mouth" was not significantly correlated in C. eos with any of the aforementioned characters. However, this angle had significant and negative correlation to these characters in C. erythrogaster. These findings indicate that the angle of mouth remains constant in C. eos throughout life but decreases as C. erythrogaster grows.

The snout-orbit and snout-mouth ratios were larger in C. erythrogaster. The ratios of snout length/head length and snout length/head depth had significant positive correlation in both species to growth, indicating that snout length changed at a faster rate than overall head size. However, the correlations were stronger in C. erythrogaster. The ratio of orbit length/snout length decreased significantly with growth in both species, indicating that snout length increased more rapidly than orbit length. However, the

TABLE 5. Correlation matrix used in determining growth correlations among morphological characters in <u>Chrosomus erythrogaster</u> from Minnesota. Coefficients significantly different from zero ($P < 0.01$) are underlined.

Symbols are as follows: TL = total length, SL = standard length, OL = orbit length, SnL = snout length, PL = postorbital length, HL = head length, HD = head depth, LSR = number of lateral scale rows, CPSR = number of caudal peduncle scale rows, DFR = number of dorsal fin rays, AFR = number of anal fin rays, CFR = number of caudal fin rays, PFR = number of pelvic fin rays, AM = angle of mouth, LM = length of mouth, and D = "drainage".

	TL	SL	OL	SnL	PL	HL	HD	LSR	CPSR	DFR	AFR	CFR	PFR	AM	LM	D	SnL/HL	OL/HL	HD/HL	ML/HL	OL/SnL	ML/SnL	HL/SL	SnL/PL	SnL/HD
TL																									
SL	.999																								
OL	.967	.965																							
SnL	.980	.977	.941																						
PL	.984	.984	.966	.967																					
HL	.991	.991	.972	.981	.993																				
HD	.989	.986	.965	.975	.985	.991																			
LSR	.365	.361	.342	.362	.339	.365	.347																		
CPSR	.221	.215	.196	.247	.217	.225	.209	.347																	
DFR	.167	.158	.132	.183	.174	.168	.171	-.014	.085																
AFR	.114	.112	.093	.099	.091	.098	.109	.058	-.116	.165															
CFR	-.056	-.054	-.066	-.048	-.087	-.067	-.087	-.010	-.002	.019	-.006														
PFR	.073	.064	.077	.049	.078	.057	.074	.024	-.049	-.006	.002	.272													
AM	-.305	-.305	-.289	-.336	-.283	-.294	-.289	-.087	.037	-.176	-.098	.001	.017												
LM	.978	.973	.952	.972	.967	.975	.971	.328	.237	.164	.096	-.038	.083	-.287											
D	-.076	-.098	-.101	-.104	-.108	-.124	-.116	-.046	-.058	.137	.097	.135	.043	-.195	-.076										
SnL/HL	.550	.540	.456	.672	.490	.525	.534	.263	.178	.131	.047	.028	-.010	-.332	.576	-.018									
OL/HL	-.852	-.852	-.734	-.871	-.852	-.863	-.859	-.351	-.209	-.158	-.064	.049	-.022	.253	-.840	.125	-.609								
HD/HL	-.395	-.401	-.423	-.417	-.435	-.443	-.323	-.195	-.201	-.033	.044	-.091	.088	.114	-.399	.085	-.142	.374							
ML/HL	-.021	-.039	-.051	.000	-.075	-.069	-.046	-.096	.100	.013	-.015	.115	.103	-.016	.148	.199	.247	.070	.201						
OL/SnL	-.780	-.776	-.665	-.850	-.753	-.777	-.778	-.352	-.196	-.145	-.052	.022	-.009	.298	-.783	.112	-.865	.915	.302	-.057					
ML/SnL	-.499	-.502	-.437	-.594	-.484	-.511	-.503	-.304	-.075	-.096	-.046	.057	.072	.263	-.411	.171	-.740	.598	.265	.459	.756				
HL/SL	-.595	-.605	-.501	-.520	-.498	-.502	-.535	-.228	.014	-.035	-.128	-.035	-.063	.283	-.532	-.163	-.410	.448	-.045	-.146	.463	.256			
SnL/PL	.176	.168	.088	.317	.075	.152	.159	.176	.125	.053	.038	.096	-.103	-.220	.209	-.078	.846	-.297	-.006	.247	-.603	-.603	-.185		
SnL/HD	.635	.630	.566	.749	.601	.635	.592	.307	.234	.129	.022	.063	-.037	-.337	.659	-.053	.914	-.676	-.531	.127	-.863	-.741	-.331	.726	

TABLE 6. Correlation matrix used in determining growth correlations among morphological characters in *Chrosomus eos* from Minnesota. Coefficients significantly different from zero ($P < 0.01$) are underlined.

Symbols are as in Table 5.

	TL	SL	OL	SnL	PL	HL	HD	LSR	CPSR	DFR	AFR	CFR	PFR	AM	LM	D	SnL/HL	OL/HL	HD/HL	ML/HL	OL/SnL	ML/SnL	HL/SL	SnL/PL	SL/HD
TL																									
SL	.998																								
OL	.954	.950																							
SnL	.979	.977	.944																						
PL	.982	.981	.934	.960																					
HL	.992	.990	.960	.980	.992																				
HD	.981	.978	.953	.964	.983	.988																			
LSR	.119	.110	.116	.089	.129	.113	.117																		
CPSR	-.146	-.148	-.168	-.186	-.151	-.161	-.177	.351																	
DFR	.004	.004	.022	.037	.021	.019	.016	-.072	.135																
AFR	.235	.229	.220	.244	.218	.234	.229	-.046	-.010	.013															
CFR	-.186	-.185	-.203	-.186	-.166	-.186	-.179	-.124	.002	-.003	.123														
PFR	.010	.005	-.028	.022	-.012	-.004	.020	.000	.095	.000	.178	.167													
AM	.156	.159	.052	.096	.163	.126	.164	.162	.040	.004	-.017	-.010	-.050												
LM	.955	.949	.944	.958	.942	.959	.949	.063	-.185	.061	.240	-.149	.008	.085											
D	.198	.201	.251	.228	.212	.217	.226	-.150	-.335	.122	.057	.023	-.080	-.027	.258										
SnL/HL	.343	.345	.318	.490	.253	.312	.289	-.091	-.191	.088	.153	-.052	.106	-.084	.373	.159									
OL/HL	-.696	-.704	-.485	-.674	-.731	-.697	-.681	-.058	.078	.010	-.190	.112	-.047	-.296	-.604	-.062	-.181								
HD/HL	-.310	-.314	-.278	-.342	-.300	-.320	-.173	.038	-.050	-.023	-.097	.099	.121	.187	-.287	-.005	-.245	.301							
ML/HL	.190	.178	.254	.234	.145	.180	.189	-.134	-.132	.151	.069	.079	.034	-.136	.445	.216	.308	.113	.035						
OL/SnL	-.700	-.707	-.530	-.762	-.676	-.684	-.659	.012	.159	-.038	-.228	.107	-.088	-.180	-.646	-.127	-.679	.842	.360	-.078					
ML/SnL	-.074	-.087	.008	-.134	-.052	-.060	-.036	-.056	.008	.089	-.053	.108	-.045	-.076	.149	.100	-.417	.250	.207	.735	.419				
HL/SL	-.297	-.325	-.159	-.235	-.185	-.191	-.195	-.005	-.022	.104	-.058	.024	-.053	-.305	-.176	.041	-.327	.297	.050	.004	.405	.250			
SnL/PL	-.041	-.043	.001	.109	-.164	-.070	-.096	-.165	-.109	.060	.102	-.011	.111	-.230	.023	.056	.851	.227	-.142	.311	-.300	-.305	-.165		
SnL/HD	.411	.414	.379	.539	.336	.392	.300	-.079	-.116	.079	.159	-.091	.016	-.162	.423	.120	.875	-.276	-.682	.219	-.682	-.412	-.266	.718	

correlations were again stronger in C. erythrogaster. The ratio of mouth length/snout length was not correlated to growth in C. eos but had significant negative correlation to growth in C. erythrogaster. This shows that the snout increased in length at a rate significantly faster than the mouth in C. erythrogaster but not in C. eos. The ratio of mouth length/head length was not correlated to overall growth in either species.

Small individuals of both species possess a relatively short snout and oblique mouth. Since angle of mouth and snout length did not vary significantly with locality in either species, the data were pooled to illustrate changes in shape of head in both of them (Table 7).

The shape of the face changes more in ontogeny in C. erythrogaster than in C. eos. In C. erythrogaster, the mouth becomes less oblique. The snout is initially shorter than the orbit in C. erythrogaster but surpasses the latter in length when the fish reaches a length of 50-60 mm. The same measurements made on a single large collection of this species from Otter Creek at County Road 6, Mower County, yielded similar results (Table 8). Corresponding changes did not occur in C. eos.

With a few exceptions, the meristic characters examined were not correlated with growth or with each other in either species. The most notable exception

TABLE 7. Changes in the proportion of selected head dimensions in various size classes of *Chrosomus erythrogaster* and *C. eos*, based on 115 specimens of each species collected in various drainage basins in Minnesota. Measurements are in millimeters.

(A) *C. erythrogaster*.

(B) *C. eos*.

TABLE 7A. C. erythrogaster.

Size interval	Number of specimens	Mean total length	Mean orbit length	Mean snout length	Mean mouth length	Mean angle of mouth	Ratio snout: orbit	Ratio snout: mouth
20-24.9	1	24.8	1.7	1.4	1.3	56^{o}	0.82:1	1.08:1
25-29.9	6	28.0	1.9	1.5	1.4	54	0.79:1	1.07:1
30-34.9	11	33.0	2.1	1.7	1.6	51	0.81:1	1.06:1
35-39.9	9	37.7	2.2	2.1	1.8	51	0.95:1	1.17:1
40-44.9	12	42.8	2.5	2.4	2.1	51	0.96:1	1.14:1
45-49.9	18	47.1	2.6	2.6	2.3	51	1.00:1	1.13:1
50-54.9	14	52.7	2.9	2.9	2.5	52	1.00:1	1.16:1
55-59.9	16	57.2	3.0	3.2	2.7	50	1.07:1	1.19:1
60-64.9	18	62.8	3.3	3.5	3.0	51	1.06:1	1.17:1
65-69.9	7	67.0	3.3	3.8	3.2	48	1.15:1	1.19:1
70-74.9	1	72.5	3.5	4.3	3.3	45	1.23:1	1.30:1
75-80	2	76.3	3.6	4.3	3.4	50	1.19:1	1.26:1

TABLE 7B. <u>C. eos</u>.

Size interval	Number of specimens	Mean total length	Mean orbit length	Mean snout length	Mean mouth length	Mean angle of mouth	Ratio snout: orbit	Ratio snout: mouth
25-29.9	7	28.4	1.9	1.5	1.4	57^{o}	0.79:1	1.07:1
30-34.9	3	32.9	2.0	1.6	1.6	58	0.80:1	1.00:1
35-39.9	17	38.7	2.3	2.0	1.8	60	0.87:1	1.11:1
40-44.9	9	42.3	2.5	2.2	1.9	58	0.88:1	1.16:1
45-49.9	21	47.2	2.7	2.5	2.2	58	0.92:1	1.14:1
50-54.9	22	53.1	3.0	2.8	2.6	59	0.93:1	1.08:1
55-59.9	8	55.7	3.0	3.0	2.6	60	1.00:1	1.15:1
60-64.9	15	61.6	3.3	3.3	3.0	60	1.00:1	1.10:1
65-69.9	10	67.3	3.6	3.6	3.1	59	1.00:1	1.16:1
70-75	3	71.2	3.7	4.0	3.7	61	1.08:1	1.08:1

TABLE 8. Changes in the proportions of selected head dimensions in various size classes of <u>Chrosomus erythrogaster</u>, based on 184 specimens taken from Otter Creek at County Road 6, Mower County, Minnesota, 24 October 1964. Measurements are in mm.

Size interval (mm)	Number of specimens	Mean total length	Mean orbit length	Mean snout length	Mean mouth length	Mean angle of mouth	Ratio snout: orbit	Ratio snout: mouth
25-29.9	1	28.1	2.0	1.4	1.3	54°	0.70:1	1.08:1
30-34.9	6	32.3	2.2	1.5	1.6	51	0.68:1	0.94:1
35-39.9	1	35.0	2.2	1.8	1.8	50	0.82:1	1.00:1
40-44.9	3	42.6	2.7	2.3	2.2	49	0.85:1	1.05:1
45-49.9	11	46.9	2.7	2.5	2.2	50	0.93:1	1.14:1
50-54.9	36	52.7	2.9	2.8	2.5	51	0.97:1	1.12:1
55-59.9	33	57.5	3.0	3.2	2.7	50	1.07:1	1.19:1
60-64.9	35	62.9	3.2	3.6	3.1	49	1.13:1	1.16:1
65-69.9	44	67.5	3.4	3.8	3.2	48	1.12:1	1.19:1
70-74.9	10	71.4	3.5	4.0	3.4	49	1.14:1	1.18:1
75-79.9	3	76.5	3.7	4.3	3.6	47	1.16:1	1.19:1
80-85	1	82.6	4.0	5.0	4.3	48	1.25:1	1.16:1

was that of number of lateral scale rows, which showed significant positive correlation to growth in C. erythrogaster but not in C. eos. The number of scale rows of caudal peduncle was not significantly correlated to size in either species, but this character was positively correlated to number of lateral scale rows in both. Therefore, the increase in number of scale rows in individuals having relatively high lateral scale row counts was due in part to an increase in scale rows on the caudal peduncle. In C. erythrogaster, number of pelvic fin rays and number of caudal fin rays were positively and significantly correlated. The biological significance of this correlation is not apparent.

Geographical Variation.

In the samples of C. eos and C. erythrogaster used for analyzing intercharacter correlation in ontogenic changes in morphological traits, the drainage from which each specimen came was given a number and incorporated into the correlation matrix. The drainages and basins were arbitrarily numbered 1-8 from north to south.

Drainages included were the Arctic (numbered 1), Red River (2), Superior (3), and Mississippi. The latter was divided arbitrarily into the upper Mississippi (4), Minnesota (5), lower Mississippi (6), Cedar (7), and Missouri (8) "drainages" for the analyses. All "drainages" were represented as equally as possible in the samples (Table 1).

No morphological traits tested were significantly correlated to "drainage" in C. erythrogaster. This species is confined in Minnesota to the Mississippi drainage below St. Anthony Falls, but since populations in separate basins apparently have little or no contact with each other, it was thought that groups exhibiting some morphological differences might have arisen even within a single drainage as was noted, for example, by Thompson (1931:279) for the Johnny darter, Etheostoma nigrum. However, the samples tested (from the Cedar basin, Missouri basin, and lower Mississippi River tributaries) did not differ significantly from each other in body proportions or meristic characters.

Although much more widespread in Minnesota than C. erythrogaster, C. eos likewise showed little geographic variation. In C. eos, "drainage" was significantly and negatively correlated to scale rows of caudal peduncle and positively correlated to length of mouth.

In order to evaluate these significant correlations, the sample of C. eos was divided into subsamples according to "drainage". The data were then graphed according to the format reviewed by Hubbs and Hubbs (1953).

The average numbers of caudal peduncle scale rows in specimens of *C. eos* from certain "drainages" were significantly different from those from other "drainages" according to the nonparametric Mann-Whitney U test.

To list all pair combinations of Means showing significant differences, and to indicate the levels of significance at which the two "drainages" of each given pair differed from each other, would be laborious. Suffice it to say that specimens from northern Minnesota averaged slightly greater in number of caudal peduncle scale rows than specimens from southern Minnesota (Fig. 3). The extreme Mean values were 23.9 (Arctic drainage, 24 specimens) and 21.5 (Cedar River "drainage", four specimens).

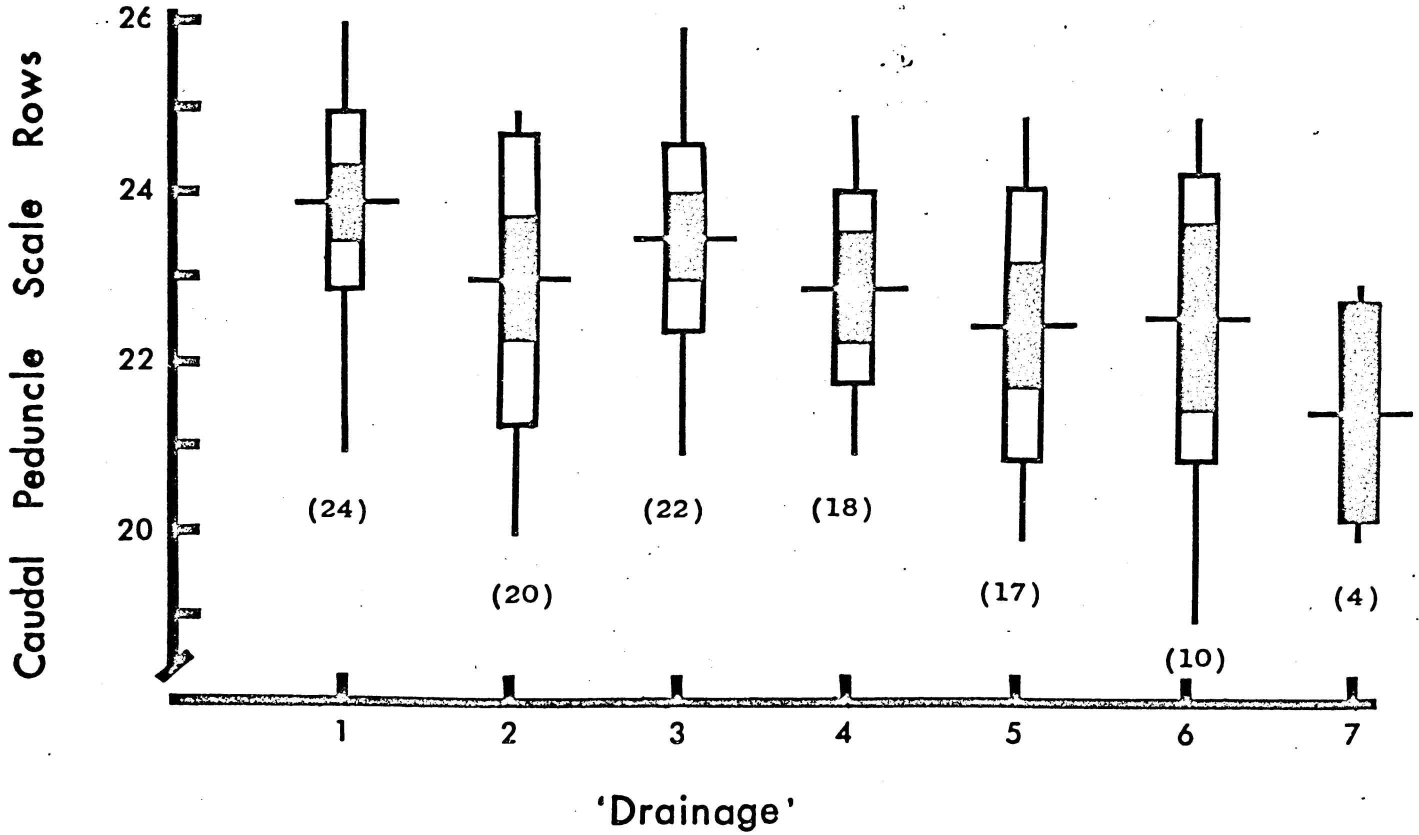
Water temperatures are probably warmer in southern Minnesota than in northern Minnesota, and certain meristic characters, including numbers of scales, are known to vary inversely with temperature in fishes (Hubbs, 1922: 365; Lindsey, 1953:219; Mottley, 1934:261; Tåning, 1952). Because of the small samples tested, however, further sampling is needed before it is known to what extent numbers of caudal peduncle scale rows vary in *C. eos* within Minnesota.

The Mann-Whitney U test also indicated that the average length of mouth in specimens of *C. eos* from certain "drainages" was greater than in specimens from other "drainages". All pair combinations of Mean values

FIG. 3. Numbers of caudal peduncle scale rows of Chrosomus eos from various drainages and river basins in Minnesota. The "drainages" are numbered as follows: (1) Arctic drainage; (2) Red River drainage; (3) Superior drainage; (4) upper Mississippi River basin; (5) Minnesota River basin; (6) lower Mississippi River basin; and (7) Cedar River basin.

The vertical line indicates the range; the horizontal line, the Mean; the open rectangle, two Standard Deviations; and the closed rectangle, four Standard Errors of the Mean.

The figures in parentheses indicate sample sizes from each of the "drainages".


Caudal Peduncle Scale Rows
26
24
22
20
(24)
(20)
(22)
(18)
(17)
(10)
(4)
1
2
3
4
5
6
7
'Drainage'

showing significant differences need not be listed here, especially since differences in length of mouth were accompanied by significant differences in total length. Since length of mouth and total length were positively correlated (Table 6), the interbasin differences noted in length of mouth are likely due largely to the fact that specimens from certain areas, notably the Minnesota and Cedar River "drainages", were larger than specimens from other places (Fig. 4). The extreme Mean values for length of mouth were 2.15 mm (Arctic drainage, 24 specimens) and 2.8 mm (Minnesota River "drainage", 17 specimens).

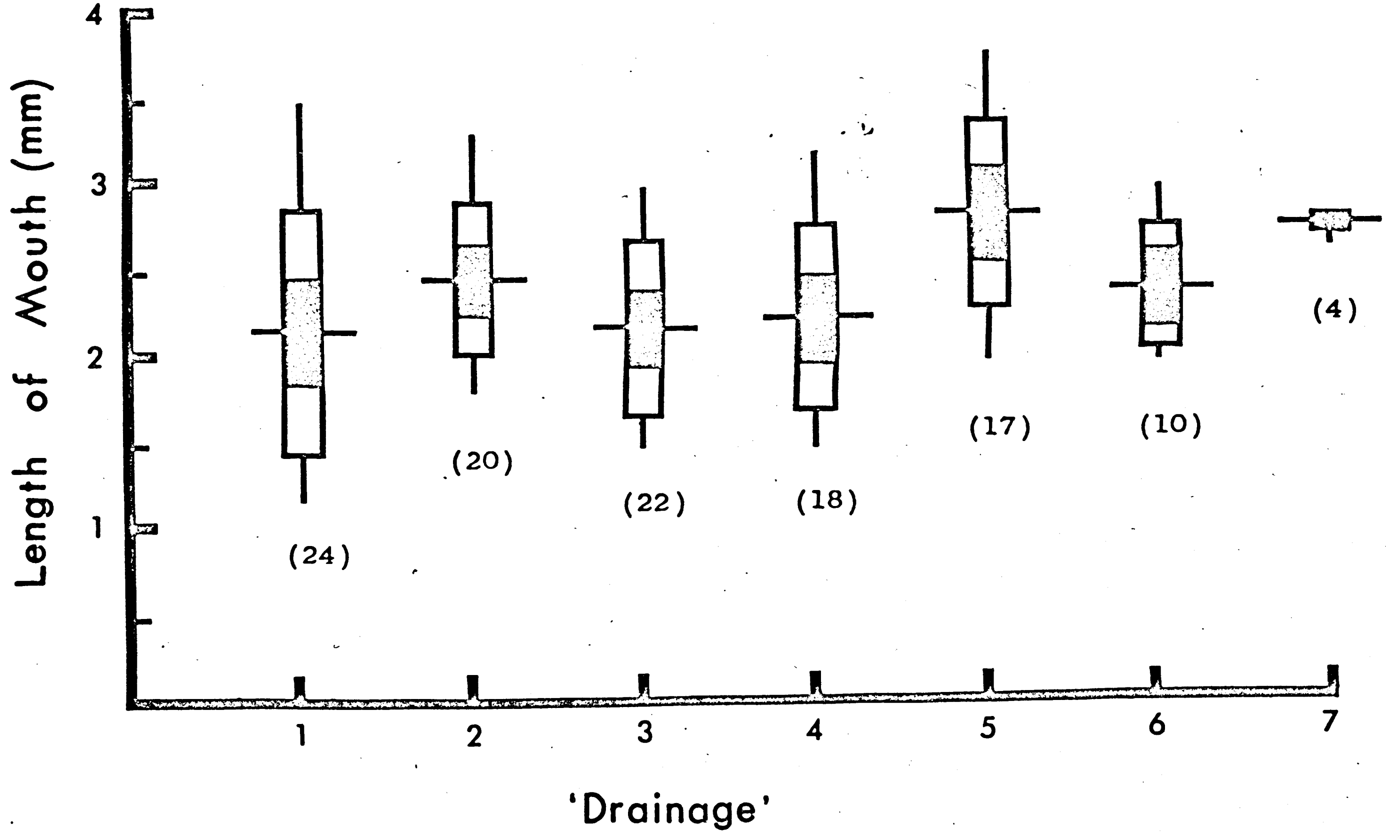
The importance of the existence of little geographic and interdrainage variation in *C. eos* is that specimens from a given drainage, such as those from southern Minnesota, are morphologically the same as those from any other part of the state, such as northern Minnesota. There is no evidence of obvious clinal variation.

Interpopulation Mean Character Differences.

The first step in analyzing for character differences between the samples of *C. erythrogaster* and *C. eos* tested was an analysis of mean character differences by computation of the standard *t* test of Student. Since no assumptions concerning knowledge or

FIG. 4. Lengths of mouths of specimens of *Chrosomus eos* from various drainages and river basins in Minnesota.

Symbols are as in Fig. 3.



Length of Mouth (mm)
4
3
2
1
(24)
(20)
(22)
(18)
(17)
(10)
(4)
1
2
3
4
5
6
7
'Drainage'

equality of mean variances were made, the following formula was used to calculate the test statistic (T):

$$T = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} .$$

T is distributed according to Student's t probability distribution with degrees of freedom (d.f.):

$$d.f. = \frac{\left(\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}\right)^2}{\frac{\left(\frac{s_1^2}{n_1}\right)^2}{n - 1} + \frac{\left(\frac{s_2^2}{n_2}\right)^2}{n - 1}} - 2.$$

The analyses showed significant differences (at 5% level of α error) between mean values of nine characters: (1) angle of mouth, (2) snout length/postorbital length, (3) snout length/head length, (4) mouth length/head length, (5) head depth/head length, (6) snout length/head depth, (7) head length/standard length, (8) orbit length/snout length, and (9) postorbital length (Table 9).

"P", the probability of misclassification (of confusing C. eos with C. erythrogaster) was determined in the present study by the formula

$$P(\text{miscl.}) = P(x_i 1 > C^* | \bar{X}_1, sx_1^2) + P(x_i 2 < C^* | \bar{X}_2, sx_2^2)$$

where C* = the point midway between the population (sample) character means, and

TABLE 9. Means, Standard Deviations, Differences between Means (*t*), and Probabilities of Misclassification (P) for sample populations of 115 specimens of *Chrosomus erythrogaster* and 115 specimens of *C. eos* from Minnesota based on measurements, counts, and ratios of 24 morphological characters. Symbols are as in Table 5. Measurements of length are in millimeters.

	C. erythrogaster		*C. eos*			
	$\overline{X}$	S.D.	$\overline{X}$	S.D.	*t*	P
TL	49.9	11.0	50.0	10.6	0.06	
SL	40.1	10.1	40.6	9.1	1.25	
OL	2.7	0.5	2.8	0.5	1.00	
SnL	2.7	0.7	2.6	0.6	1.00	
PL	4.7	1.2	5.1	1.2	2.53	
HL	10.2	2.4	10.6	2.3	0.41	
HD	6.6	1.5	6.7	1.4	0.58	
LSR	83.5	2.5	83.1	2.5	1.21	
CPSR	22.8	1.5	23.1	1.5	1.52	
DFR	8.0	0.3	8.0	0.1	0.00	
AFR	8.0	0.2	8.0	0.3	0.00	
CFR	18.9	0.6	19.0	0.3	1.61	
PFR	8.0	0.2	8.0	0.2	0.00	
AM	50.9°	2.6	59.1°	2.8	23.03**	12.03
LM	2.39	0.57	2.37	0.57	0.27	
SnL/HL	0.268	0.018	0.250	0.013	9.00**	55.36
OL/HL	0.274	0.024	0.269	0.019	1.79	
HD/HL	0.653	0.020	0.638	0.021	5.77**	71.14
ML/HL	0.235	0.012	0.223	0.016	6.32**	66.05
OL/SnL	1.032	0.154	1.082	0.107	2.94**	84.54
ML/SnL	0.881	0.070	0.896	0.067	1.67	
HL/SL	0.255	0.010	0.261	0.009	4.76**	75.28
SnL/PL	0.586	0.043	0.524	0.037	11.92**	43.63
SnL/HD	0.410	0.031	0.392	0.027	4.86**	75.66

**Highly significant ($P < 0.01$).

x_i = the proportion of a population expected to occur farther away from its mean than point C* if that population is distributed as a "normal curve" around its mean (see discussion of Kim *et al*, 1963).

In the "populations" of *C. erythrogaster* and *C. eos* tested only two characters, angle of mouth and the ratio of snout length/postorbital length, yielded P values of less than 50% (Table 9). Each of the other characters whose means were found to differ significantly between the two species would, if used alone, be expected to cause misclassification more than 50% of the time.

Anomalies.

Anomalies in the structure and numbers of fins have been reported for various fishes (see, for example, Cross and Moore, 1952:411; Crossman, 1961:236; Greenbank, 1945:178; Marr, 1945:115). The following anomalies were observed in fins of *C. eos* and *C. erythrogaster*.

C. eos:

A male, total length 51.6 mm, lacking pelvic fins. Otherwise externally normal. (In University of Minnesota Coll. No. 18132. From Mud River, 0.2 mile below Grygla, Marshall County, 27 June 1955. Seined by "Tasker *et al*").

A female, total length 60.3 mm, lacking the right pelvic fin; the left pelvic fin has six fin rays rather than the usual eight. Otherwise externally normal. (In J. C. Underhill Field Coll. 64-010, at Zoology Building, University of Minnesota. From Mississippi headwaters, Itasca Park, Clearwater County, 30 July 1964. Seined by R. B. Forbes and J. C. Underhill).

A male, total length 50.6 mm, lacking the right pectoral fin. Otherwise externally normal, including a fully formed left pectoral fin having 15 fin rays. (In unnumbered collection at Zoology Building, University of Minnesota. From Deming Lake, Itasca Park, Hubbard County, T143N-R35W-S30, 4-7 July 1967. Taken in minnow trap by R. H. Stasiak).

A female, total length 52.0 mm, with no visible dorsal fin; in place of a dorsal fin is a single spine-like protrusion, not erupted through the skin. Otherwise externally normal. (In University of Minnesota Coll. No. 11514-17. From Knife River, St. Louis-Lake Counties, 27 June 1940. Seined by J. Moyle *et al*).

C. erythrogaster:

A male, total length 60.0 mm, with a small dorsal fin having two fin rays rather than the usual eight. Otherwise externally normal. (In J. C. Underhill Field Coll. 64-027, at Zoology Building, University of

Minnesota. From Otter Creek at County Road 6, Mower County, 24 October 1964. Seined by J. C. Underhill *et al*).

REPRODUCTION

Schooling Behavior.

Chrosomus erythrogaster is a schooling fish. Spawning behavior of this species seems related to its social habits. Smith (1908:14) observed members of a school of *C. erythrogaster* to spawn simultaneously in a "compact body". This species (Hankinson, 1932:415) and *C. oreas* (Raney, 1947:126) are also known to use nests of gravel constructed by other fishes as breeding sites.

The relations between *C. erythrogaster* and the creek chub (*Semotilus atromaculatus*), a nest-building minnow, were observed in the headwaters of the Zumbro River, Dodge County, from 22 May through 1 June, 1966. Schools of redbelly dace inhabiting a beaver dam pool were observed to congregate over depressions hollowed out by large creek chubs. Two, sometimes three, schools of dace were present in the course of the observation period.

The creek chubs did not construct nests of stones while excavating these depressions, as members of this species are known to do (Raney, 1940a:131; Reighard, 1910:1127). Stones and gravel of a size convenient for nest construction were not present in the pool or in adjacent parts of the stream. Thus the creek chubs carried out one phase of their pre-spawning behavior, but due to lack of nest materials were unable to construct "normal" spawning depressions.

The depressions were made by creek chubs that worked alone. During these endeavors they were literally swarmed over by schools of redbelly dace. The dace frequently assumed vertical positions with heads downward, seemingly seeking food, possibly eggs, in the substrate (see Raney, 1940:401). The dace did this although no spawning activity by creek chubs was ever observed. The creek chubs did not react unfavorably to the engulfing hordes of dace, but were quick to drive away stoneroller minnows (_Campostoma anomalum_) that came near their excavations.

The schools of _C. erythrogaster_ at times moved _en masse_ away from holdings of creek chubs in order to tour the pool and eventually return. Individuals on occasion briefly left their school. However, they soon returned either to the one they had left or to another one. Spawning by schools of redbelly dace as a group was not observed. Those attempting to spawn swam away from the main body, usually in twos or threes.

Spawning Behavior.

The breeding activities of _C. erythrogaster_ were described in detail by Smith (1908). He observed spawning in various circumstances, but the basic pattern was as follows (p. 13):

> "... two males spawn with the single female as follows: One on each side presses the side of his head against that of the female, all three facing upstream. The two males then crowd laterally against the female, held between them ...; their entire flanks are thus pressed against the sides of the female. While the males are in this position, a rapid vibration of their bodies occurs. The wave of pressure begins at the anterior end of the body and passes backward as a sidewise undulating movement. Other males may attempt to crowd in. So far as observed, the female remains passive."

Smith observed C. erythrogaster to spawn both in the open and among pebbles on the bottom, and considered the latter more effective. Redbelly dace observed in the present study invariably attempted to spawn in the open water, with no apparent success. The females resisted, successfully, efforts by males to force them against the substrate.

Females sometimes left their school spontaneously, an action that appeared to initiate the pre-spawning chase. Females not joined by males after setting forth usually returned immediately. A female in a school would on occasion be bumped by a male. This action seemed deliberately intended to drive her into the open. If the female then took flight, the male and a companion or two would pursue her. "Spawning groups" usually consisted of two males and one female. However, couples consisting of one member of each sex were frequently observed, and as many as four males were seen to chase one female.

In no case did females seem receptive to males. It is possible that spawning occurred within the schools where I could not detect it, that it occurred while I was not present, or that other redbelly dace spawned successfully in other parts of the stream while the investigation was in progress or at another time. The most active breeding attempts were observed on 28 May. After 1 June the schools gradually dispersed, or at least left the pool. The water was turbid in mid-June and no more reproductive behavior was observed.

Spawning by C. eos was not observed in the present study. The act, as described by Hubbs and Cooper (1936: 73), is similar to that of C. erythrogaster. The female is attended by from one to eight males (loc. cit.).

Eggs released by the C. erythrogaster studied by Smith (op. cit.:13) were dispersed among pebbles in the substrate of the stream. C. eos observed in an artificial pond by Cooper (1935:141) deposited eggs in masses of filamentous algae. The dace darted from one mass to another, performed a short spawning embrace in each mass, and left a few ("5 to 30") eggs scattered among the algal filaments. It is not known if this behavior prevails in natural surroundings. Beckman (1952:46) stated that C. eos spawns "on gravel bottoms in shallow, rapid streams" as well as in filamentous algae.

Breeding Color.

Redbelly dace are named for the scarlet color that is present on their abdomens, especially in breeding males, in spring and summer. Smith (1908:10) thoroughly described this coloration in *C. erythrogaster*:

> "... males were found to be marked on each side of the abdomen with a broad longitudinal stripe of the most vivid and brilliant scarlet that I have ever seen. This stripe starts just back of the operculum and runs immediately below the lower of the two lateral dark bands ... and parallel to it, reaching almost to the caudal fin. There is also a small red spot just below the mandible on each side. In some specimens the lateral bands of red are faint except just behind the operculum. In the more highly colored males the entire abdomen is covered with red, and there is a red spot in the anterior part of the root of the dorsal fin. The pectoral and pelvic fins, and the anal fin, are bright lemon yellow; the dorsal fin and tail are faintly marked with pale yellow. There is a small spot of yellow on the ventral side of the body at the base of the caudal fin, and another in the gular region."

The breeding colors probably serve in sex recognition by breeding *C. erythrogaster* (Smith, p. 17).

The development of breeding color in *C. erythrogaster* and *C. eos* in Minnesota was studied in 1965.

Mature *C. erythrogaster* collected in Otter Creek, Mower County, on 9 May exhibited yellow coloring on their fins and ventral surfaces. The yellow was best developed on the pectoral, pelvic, and anal fins, but did not cover the whitish distal margins of any of the body fins. Scarlet coloration was not yet present; streaks and patches of pink and, occasionally, red-orange, were noted. Red-orange is apparently an intermediate color between pink and the development of scarlet. Reddish coloring in the fishes examined was brightest above the pectoral fins, apparently being first manifest there. Areas above the anal and pelvic fins were also among the first places where pink was visible.

An examination of abdominal scales showed that the pinkish hues first appeared at their margins. Flecks of pink were scattered about on a few scales, obviously destined to increase in size and intensity until the scale would appear solid red in color.

Some mature males collected in the headwaters of the Zumbro River, Dodge County, on 19 May were still in the "pinkish and diffuse" phase, but scarlet was well developed in most. The red coloration had diffused over the abdomen and also occurred in miscellaneous places, such as the lips, throat, and opercula. The caudal peduncle, in males in this and other samples taken later, was seldom extensively covered with red -- here yellow persisted even in the most highly colored individuals.

Specimens of C. eos taken 15 and 20 June in the headwaters of the Mississippi River at Itasca Park, Clearwater County, showed virtually no red coloration. The fins, abdomen, and caudal peduncle were vivid yellow in mature individuals, however. Red was present in varying amounts on specimens taken 23 June, and was noted in specimens taken later in June and in July. Scarlet was generally less widely spread over the body in C. eos than in the C. erythrogaster observed in southern Minnesota, but was, when developed, equally as bright. Scarlet apparently never formed in some mature male C. eos taken at Itasca, although the yellow coloration became more intense in summer.

It is possible that relatively cool temperatures limited the proliferation of scarlet in the C. eos examined, since they lived more than 250 miles north of the C. erythrogaster studied. Assuming that both species are capable of attaining equally bright colors, observations by other authors indicate that temperature may influence their brightness. Kendall and Dence (1929: 301) found scarlet poorly developed in C. eos in New York in midsummer, whereas C. erythrogaster observed by Hemphill (1957:53) in Mississippi were "brilliantly colored" on 26 March 1955. Intensity of coloration in both species in Minnesota subsided after breeding season, but faded breeding colors were present in some individuals through September,

Females of both species exhibited bright yellow breeding colors but relatively little red. Large females on occasion developed scarlet coloring, a phenomenon also noted by Smith (op. cit.:11).

Saphir (1934:866) stated that the breeding color of *C. erythrogaster* is probably due "to the action of substances having either a stimulating effect upon the sex glands of the fish, such as prolan, or having an effect similar to that of the estrus producing hormones, such as Yohimbine." Whatever the mechanism, it seems logical that it is the same in both species.

Breeding Tubercles.

Various kinds of minnows develop tubercles, or "pearl organs", in breeding season. The roles of these tubercles in breeding activities were apparently first discussed by Reighard (1903:531; 1904:211). In redbelly dace, males possess small but distinct tubercles on their fins and over most of the body. Females have smaller tubercles, usually restricted to the shoulders and back, but more widely distributed in some large females.

Smith (1908:11) characterized a typical well developed tubercle on the body of a male *C. erythrogaster* as a pointed spine, pointing obliquely backward, and occurring as a thickening of the epidermis over the middle and posterior margin of the scale.

Smith (p. 17) stated that pearl organs help the male dace keep his position beside the female when spawning, and aid in holding the female when a male interlocks one of his large and tuberculated pectoral fins "between the pectoral fin and the body of the female ... ."

Smith's description of the pearl organs of C. erythrogaster, although detailed, did not specifically mention the series of regular rows of pointed tubercles that form on scales of the breasts of some breeding males anterior to the pectoral fins (Plate 1). These tubercles, when present, may assist males in the spawning actions noted by Smith. The degree of development of these breast tubercles is highly variable and many mature males lacked them. They were not strongly developed in any females. They disappeared in late summer.

These "comb rows" of breast tubercles were apparently first noted by Hubbs and Ortenburger (1929: 90). Hubbs and Brown (1929:28) observed the same arrangement of tubercles in Chrosomus neogaeus and stated that the similarity was "... too definite to indicate anything but direct relationship." Similarities in breeding color, breeding behavior, and the arrangement of these rows of tubercles suggested to Koster (1939: 205-6) that certain members of the genera Pfrille (= Chrosomus), Margariscus (= Semotilus), Couesius (= Hybopsis), and Clinostomus are phylogenetically close.

PLATE 1. Male _Chrosomus erythrogaster_, showing breeding tubercles, taken in the headwaters of the Zumbro River, Dodge County, Minnesota, 19 May 1965. Side view (at top) and ventral view (at bottom). Ventral view shows heavily tubercled scales anterior to pectoral fins. Photographs by Professor William D. Schmid of the University of Minnesota.

Sex Ratios.

Smith (1908:12) sexed 220 C. erythrogaster taken over spawning beds and noted an overwhelming (6.5:1) ratio of males over females. He stated (p. 17): "The excessive number of males ... is perhaps correlated with the method of spawning, since two males spawn with a single female."

The C. erythrogaster observed here behaved in the same way. However, the sex ratios noted here were different from those reported by Smith. Of 358 specimens taken 19 May 1965 in the headwaters of the Zumbro River, Dodge County, 253 were females and 105 were males (ratio 2.41:1). In samples from the same place taken in 1966 on 4 June and 12 October, the ratios were nearly 1:1 (Table 10). All size classes available were used in the present study in determining sex ratios. However, when only sexually mature specimens ($\geq$50 mm) were included, the ratios observed were not substantially different.

My samples were not confined to spawning beds and were taken in autumn as well as in spring. As Smith (p. 12) recognized, sex ratios may vary in different places and at different times. Sampling error may also have contributed to the discrepencies between the present observations and those of Smith.

A sample of 204 C. eos taken in minnow traps in

TABLE 10. Sex ratios observed in three samples of *Chrosomus erythrogaster* taken in the headwaters of the Zumbro River, Dodge County, Minnesota.

A. 19 May 1965

Size interval (total length, mm)	Number of specimens	Females	Males	Ratio females: males
20-29.9	1	1	0	--
30-39.9	13	7	6	1.17:1
40-49.9	25	16	9	1.78:1
50-59.9	146	91	55	1.65:1
60-69.9	151	118	33	3.58:1
70-80	22	20	2	10.00:1
TOTAL	358	253	105	2.41:1

B. 4 June 1966

30-39.9	6	5	1	5.00:1
40-49.9	5	3	2	1.50:1
50-59.9	17	10	7	1.43:1
60-69.9	94	32	62	0.52:1
70-79.9	84	52	32	1.63:1
80-90	3	3	0	--
TOTAL	209	105	104	1.01:1

C. 12 October 1966

30-39.9	1	0	1	--
40-49.9	15	8	7	1.14:1
50-59.9	43	17	26	0.65:1
60-69.9	19	7	12	0.58:1
70-79.9	12	10	2	5.00:1
80-90	5	5	0	--
TOTAL	95	47	48	0.98:1

Deming Lake, Hubbard County, 4-7 July 1967 by Mr. Richard H. Stasiak contained 163 males and 41 females (ratio 3.98:1). The apparent concentration of _C. eos_ at this sampling site indicates that it may have been a spawning area.

Sexual Cycles.

Sexual cycles of _C. erythrogaster_ were studied in the headwaters of the Zumbro River, Dodge County, in 1966. Changes in gonadal weight expressed as percent of total weight were recorded for mature specimens from 20 April through 12 November. The percent gonadal weight was highest in both sexes on 21 May (Table 11). Gonadal weight in females increased markedly throughout May and reached its peak in the latter part of that month, at the height of breeding season.

Fecundity.

Many studies have been made concerning the fecundity of fishes, and no attempt was made to review all of them here. A detailed list was compiled by Carlander (1950 and 1953).

Carlander (1950:9) gave three basic methods for estimating fecundity: (1) direct counts of the eggs in ovaries, (2) counts or estimates made when females are "stripped" of their eggs, and (3) "estimates of total number of eggs from actual count of the number of eggs

TABLE 11. Gonadal weights of <u>Chrosomus erythrogaster</u> in samples taken in the headwaters of the Zumbro River, Dodge County, Minnesota, in 1966. Measurements are in millimeters. Weights are in grams.

A. Females

Date	Number of specimens	Mean total length	Mean total weight	Mean gonad weight	% Gonad weight / total weight
20 Apr	8	69.0	3.267	.145	4.44%
4 May	6	69.0	3.580	.208	5.82
21 May	8	72.3	4.292	.847	19.73
4 Jun	10	68.1	3.677	.531	14.44
26 Jun	10	68.7	3.173	.314	9.90
24 Jul	10	67.3	2.598	.082	3.16
21 Aug	8	73.0	3.783	.076	2.01
25 Sep	9	73.2	3.421	.098	2.86
12 Oct	10	68.0	2.568	.067	2.61
12 Nov	1	76.5	3.794	.100	2.64
B. Males					
20 Apr	2	64.7	2.496	.021	0.84%
4 May	7	68.3	3.295	.048	1.46
21 May	5	67.4	2.736	.041	1.51
4 Jun	11	65.0	2.709	.029	1.07
26 Jun	5	64.8	2.475	.015	0.61
24 Jul	5	58.2	1.761	.007	0.40
21 Aug	5	61.5	2.215	.009	0.41
25 Sep	5	63.4	2.487	.017	0.68
12 Oct	10	64.1	2.243	.010	0.46
12 Nov	2	62.4	2.192	.006	0.30

in a given volume or weight and multiplied by the total volume or weight of the ovaries."

The latter method basically involves determining the weight or volume of an ovary, finding the weight or volume of a sample of that ovary, counting the eggs in the sample, and deriving an estimate of the total number of eggs present by solving the proportion

$$\frac{\text{weight or volume of sample}}{\text{number of eggs in sample}} : \frac{\text{weight or volume of ovary}}{\text{total number eggs in ovary}}.$$

In a study of the fecundity of the sea lamprey, *Petromyzon marinus*, Applegate (1950:79) employed both the "gravimetric" and "volumetric" methods on the same ovaries so that the accuracy of these two methods could be compared directly. He found little difference between them. The errors in estimates made volumetrically ranged from 0 to 10.4 percent, with an average of +3.2 percent. Errors in gravimetric estimates ranged from 0 to 9.7 percent, with an average of +2.5 percent. He favored the gravimetric approach for subsequent analyses because this technique was more accurate and rapid.

Fecundity has been determined for several native North American minnows. In a majority of these studies direct counts of the eggs present rather than estimates were made, and, although not all of the authors said so specifically, minute and yolkless eggs were most certainly excluded from the counts. Examples are: Black (1945: 460) for *Notropis volucellus*, Carlson (1967:365) for

Pimephales promelas, Dobie *et al* (1956:114) and Westman (1938:59) for *Pimephales notatus*, Fry (1936:69) for "*Hesperoleucus venustus*", Harrington (1948:90) for *Notropis bifrenatus*, Washburn (1948:342) for *Semotilus atromaculatus*, and Weisel and Newman (1951:189) for *Richardsonius balteatus*.

In the present investigation an attempt was made to determine with what accuracy volumetric and gravimetric estimates of fecundity could be made for *Chrosomus erythrogaster*.

Ten adult females, collected in the headwaters of the Zumbro River, Dodge County, were used. The ovaries are considerably larger in these minnows in the spring breeding season than at other times. Therefore five specimens taken on 4 June 1966 and five collected on 12 October 1966 were used in order to see what effect variations in the overall size of the ovary had on the accuracy of the estimates obtained.

Although the numbers of eggs present in ovaries of females taken in spring were greater than those of females taken in autumn (averaging 13,488 in specimens from the 4 June sample and 11,302 in specimens from the 12 October sample for an overall average of 12,395), the increase in size of ovaries in breeding *C. erythrogaster* is apparently accomplished more through the enlargement in size of the mature ova present. Large and mature ova averaged 1.3 mm in diameter in spring, but the largest ova in females taken in autumn rarely exceeded 0.7 mm in diameter and few approached this size.

The size gap between the largest and smallest ova in ovaries of breeding female C. erythrogaster was spanned by eggs of all intervening sizes, but the simultaneous maturity of great numbers of ova in spring and early summer indicates that the breeding season of this species in Minnesota is at its height at that time (see Hickling and Rutenberg, 1936:311). Cooper, however (1935:141), noted two size classes of mature eggs in females of the closely-related C. eos in Michigan, suggesting to him that a female might spawn more than once a year.

Volumetric determinations were made in the present study by dropping ovaries and samples therefrom into Klett test tubes marked with a circumferential white line, then withdrawing the water displaced with finely calibrated serological pipettes. Gravimetric determinations were made by weighing the same ovaries and their sample sections to the nearest milligram on a Mettler Balance.

Preliminary analyses (data not recorded herein) indicated that samples of eggs taken according to the method of Applegate (p. 70), in which "a sample section was removed from the middle of the length of the ovary", yielded better estimates than samples removed as pieces from various parts of the ovary, as some workers (e.g., Raney and Webster, 1942:147; Reynolds, 1965:422; Stone, 1938:243) have used.

The lampreys studied by Applegate have a single, elongate ovary, and his estimates were based on one longitudinal section. C. erythrogaster has two ovaries, each occurring as a lobe directly to either side of the midline of the coelomic cavity and compressed between the kidneys dorsally and the swim bladder and viscera ventrally. A longitudinal section was cut from each of these two lobes and a fecundity estimate was made using each slice. The two estimates were averaged to give the final estimate for that fish.

Another modification was used in the gravimetric analyses performed here. Instead of weighing ovaries and their sample sections directly, these were placed in a beaker and water of predetermined weight. The weights of ovaries and samples were then determined by subtracting the weight of beaker and water from the weight of beaker, water, and eggs together.

This step was necessitated by evaporation while ovaries and samples were being weighed. Weight losses occurred despite the removal of excess moisture by wrapping ovaries in absorbent paper towels prior to weighing. The water loss was proportionately greater in the samples than in the intact ovaries, because a relatively greater surface area was exposed. The samples were small enough that the loss of water reduced their weights substantially.

Thus, although exposure to air caused loss of water from both intact ovaries and their samples (causing the number of eggs present to be attributed to a weight lighter than the basic wet-weight), the effect was greater in the samples. Because of this, estimates made by this procedure were consistently too high. An alternate modification would be to use dry- instead of wet-weight (Katz and Erickson, 1950:176).

The gravimetric method was found to be more accurate than the volumetric method in the present study, although neither was particularly good (Table 12). In the 4 June specimens, the average percentage error in volumetric determinations was 16.4%, and in gravimetric determinations, 9.5%. In the 12 October specimens, the average percentage error in volumetric determinations (on two fishes) was 144.5%, and in gravimetric determinations, 17.1%.

These errors are considerably higher than those reported by others (as Applegate, op. cit.:79, Vladykov and Legendre, 1940:219) who checked the accuracy of their estimates through total counts. Most authors did not deal with tiny and undeveloped ova, as I did.

TABLE 12. Comparison of the accuracy of volumetric and gravimetric methods of estimating fecundity in *Chrosomus erythrogaster*, based on 10 females taken in the headwaters of the Zumbro River, Dodge County, Minnesota, in 1966. Specimens 1-5 were collected on 4 June; specimens 6-10, on 12 October.

SPECIMEN NO.	1	2	3	4	5	6	7	8	9	10
Total length (mm)	70.4	77.9	77.2	74.5	72.4	81.5	78.7	58.7	74.7	79.5
Total weight (g)	4.691	5.791	5.536	5.222	5.606	4.021	4.150	1.650	4.250	4.674
Number of eggs, actual counts	11380	11591	13002	17831	13638	13735	9030	5708	9147	18888
Number of eggs, estimated volumetrically	13250	10501	12215	20400	18526	5721	29849	--	--	--
Percent error	+16.4	-9.4	-6.1	+14.4	+35.8	-58.3	+230.6	--	--	--
Mean percent error (absolute)			16.4%					144.5%		
Number of eggs, estimated gravimetrically	12561	12965	15276	17849	12589	16164	8947	7748	11000	20966
Percent error	+10.4	+11.9	+17.5	+0.1	-7.7	+17.7	-0.9	+35.7	+20.3	+11.0
Mean percent error (absolute)			9.5%					17.1%		

Such eggs are numerous even in the ovaries of breeding redbelly dace, so an attempt at determining total fecundity required their inclusion. They are dispersed irregularly throughout the ovary and are numerous in areas of contact between the ovary and surrounding peritoneal membranes. They are difficult to count and probably produce sampling errors in numbers of eggs of sections taken from the ovary.

Total counts tell the absolute numbers of ova present. However, it is realized that total counts are not necessarily the absolute measure of fecundity, in which case the production of viable young is the ultimate measure.

Only two ovaries from females taken 12 October were measured volumetrically, but, as the error of 144.5% indicates, this method does not seem useful for comparatively small ovaries such as those in redbelly dace in autumn. It was impossible to accurately judge the amount of water displaced by the sample sections cut from these ovaries, because the sections were too small. One possible solution is to use larger sections. However, such a procedure is self-defeating in that one would be counting the eggs of samples comprising a substantial portion of the ovary in order to make accurate estimates.

Since the purpose of this kind of study is to use the smallest possible sample that will yield accurate estimates, a method necessitating the use of samples that comprise almost half the ovary logically compels the investigator to either count all the eggs in the ovary or to use a faster method that will still give accurate estimates. Other possible methods include the determination of the size and number of eggs present through mathematical formulas after an initial volumetric determination of the size of the ovary has been made (Vladykov and Legendre, loc. cit.) or to make an estimate through prepared tables based on the size of individual ova (Von Bayer, 1910:1012-13).

It would be desirable to know what levels of accuracy might be expected when a sample of particular weight or volume relative to that of the whole ovary is used in estimating fecundity, but to determine this would require comparison of estimates to actual counts for so many ovaries that this undertaking was beyond the scope of the present study. Furthermore, no particular correlation between the size of samples relative to the size of ovaries from which they came and the accuracy of the estimates obtained was noted. Errors in technique and in sampling were apparently more important. Nevertheless, the average percentages of total ovary weight and volume occupied by the samples used in this study will be given: For 4 June,

average percent of $\frac{\text{sample weights}}{\text{total ovary wts.}}$ (5 fish) = 30.9%, and average percent of $\frac{\text{sample volumes}}{\text{total ovary vols.}}$ (5 fish) = 32.4%.

For 12 October,

average percent of $\frac{\text{sample weights}}{\text{total ovary wts.}}$ (5 fish) = 18.9%, and

average percent of $\frac{\text{sample volumes}}{\text{total ovary vols.}}$ (2 fish) = 28.2%.

The average percentage errors given in Table 12 are termed "absolute". This means that the individual percentage errors were summed together regardless of whether they were positive or negative, and then divided by the number of specimens tested to give the average error. Regarding this method of determining average errors, Applegate stated (p. 79):

> "Although in most cases this statistic might produce an inaccurate result, it is felt that in this instance its application is justified. A mean error based on the algebraic sum of deviations expressed in numbers of eggs allows individual specimens (such as a small one of low egg count) to influence the results unduly, i. e., a female, for example, containing only 25,000 eggs [sea lampreys may have more than 100,000] and for which there is a plus or minus 1,000 eggs deviation between calculated and actual totals has a large percentage error. ... an equal numerical deviation in a larger and more productive specimen results in a much lower percentage error. It follows, then, that if errors expressed in numbers of eggs tend to remain more or less constant ..., too many small test specimens or too many large test specimens in a series will undoubtedly render too high or too low a mean error."

For these reasons, the average errors in Table 12 were calculated according to Applegate's method.

Counts of eggs in five adult females of *C. eos* taken in 1965 in the headwaters of the Mississippi River, Itasca Park, Clearwater County, indicated that fecundity in this species is similar to that of *C. erythrogaster*. The counts in two specimens taken 15 June and three taken 25 June were, respectively, 12,910, 13,235, 25,623, 12,571, and 10,507, for an average of 14,969.

Finally, it should be noted that methods of estimating fecundity may be made obsolete by machines that count the ova automatically, apparently with negligible error (Boyar and Clifford, 1967:361).

Hybridization.

Species of *Chrosomus* hybridize with each other and with other kinds of minnows. The most common combination known is *C. eos* x *C. neogaeus* (see, for example, Bailey and Allum, 1962:40; Greeley and Bishop, 1932:84; Greeley and Greene, 1931:86; New, 1962; Taylor, 1954:42). This hybrid is said to be abundant in certain places, sometimes moreso than either parent species (Greeley and Greene, *loc. cit.*).

The morphology of the *C. eos* x *C. neogaeus* hybrid was discussed in detail by New (*op. cit.*). He found hybrids that were morphologically intermediate in several characteristics, including pigmentation, size of mouth, and length of intestine (p. 148). However, he also found specimens that were intermediate in some traits between the F_1 hybrids and the presumed parents, or closer to one parent than to the F_1 hybrid. His method of dealing with such specimens was to include them with "the parental form they most closely resembled thus increasing the range of variation (loc. cit.)."

These considerations are pertinent to the present study, for collections taken along Minnesota's "North Shore" (the boundary of Lake Superior) and catalogued as *C. eos* in the University of Minnesota collection contain many *C. neogaeus* and specimens that lie morphologically between this species and *C. eos*, often resembling one more than the other.

In attempting to determine the taxonomic status of these specimens, New's paper was referred to extensively here. It was concluded that certain problems are as yet unresolved.

New's inclusion of individuals that were "closer to one parent than to the F_1 hybrid" with "the parental form they most closely resembled" was done for "increasing the range of variation." It is felt here that pooling hybrids with a parental type obscures what might be the true genotype of the animal. Is it the offspring of a hybrid crossed to one of the parent species, or is it an individual whose ancestry includes a hybrid in some past, but specifically undetermined, generation? I do, however, sympathize with this action of New because even the relatively few specimens examined here that lie between *C. eos* and *C. neogaeus* exhibit a wide range of variability and in some cases are perhaps most conveniently regarded as "pure" *C. eos* or *C. neogaeus*.

Resemblance of hybrids to one parent species or the other indicates that backcrossing or introgression occurs. New mentioned both these possibilities, although in regard to backcrossing, he was aware that fertility of hybrids of *C. eos* and *C. neogaeus* has not yet been documented (p. 150).

Although New considered intestinal length as useful for separating *C. eos*, *C. neogaeus*, and their hybrids, and diagrammed the intestines of all three (p. 148-9), he did not actually measure any. The intestine is longest in *C. eos*, shortest in *C. neogaeus*, and of intermediate length in the hybrid, but deviations that "may be the result of backcrossing (p. 149)" occur.

In the present study, certain external characters and length of intestine presented problems in determining to what generation certain hybrid specimens from Collections 12091 and 13289 belonged. Seven of these specimens were intermediate between *C. eos* and what I envisage as a "typical" F_1 hybrid based on the criteria given by New.

Collection 12091, taken in the Arrowhead River, Cook County, on 21 August 1941, contains 32 specimens.

Twenty-two (six males, 16 females) are C. eos. Three (two females and a small, unsexed individual not used in calculations) are C. neogaeus. One female is a "good" F_1 hybrid. Six females are hybrids of undetermined parentage which, in the body proportions measured, lie between F_1 hybrids and C. eos (Table 13). The basic feature placing these specimens in the category of "undetermined generation" is the presence in all of them of an intestine that is more strongly looped (i.e., longer) than that drawn by New for F_1 hybrids, but less strongly looped (i.e., shorter) than in C. eos.

The cause of the intermediacy noted, whether due to backcrossing, introgression, or individual variation, is unknown. The occurrence of backcrossing has not been proved, so a demonstration of this phenomenon would be of importance. That the morphology of some specimens noted here is possibly explained by backcrossing, is, of course, not considered as proof of backcrossing. However, if backcrossing does occur in nature, one can see why the hybrids show a range of variability. New observed that adult female hybrids in breeding season had large ova that resembled eggs of the parent species, indicating that hybrids may possibly be fertile.

Collection 13289, taken in the Cascade River, Cook County, on 9 September 1941, contains 12 specimens. Nine (six females, three males) are C. eos. One female is C. neogaeus. One female is a "good" F_1 hybrid. One female

TABLE 13. Comparison of certain body proportions of <u>Chrosomus eos</u>, <u>C. neogaeus</u>, and their hybrids, based on specimens collected in the Arrowhead River, Cook County, Minnesota, on 21 August 1941 (University of Minnesota Collection No. 12091). Ratios are expressed in thousandths of Standard Length.

Character	<u>C. eos</u>	Hybrids, generation undetermined	F1 hybrid	<u>C. neogaeus</u>
	(16♀♀, 6♂♂)	(6 ♀♀)	(1 ♀)	(2 ♀♀)
Mean Standard l.	36.7 mm (29.6-46.0)	41.6 mm (36.4-44.5)	45.7 mm	36.1 mm (34.8-37.4)
Mean mouth angle	61° (57-65)	58° (56-60)	57°	55° (54-56)
Mean ratio Snout l. / Standard l.	062 (057-068)	068 (067-070)	068	076 (075-076)
Mean ratio Mouth l. / Standard l.	058 (051-069)	071 (065-077)	070	086 (both 086)

is a hybrid intermediate between C. eos and a "typical" F_1 hybrid of New. All hybrids noted are females. New (p. 150) termed male hybrids "essentially non-existent."

An attempt was made here to assign the hybrids in Collection 13289 to their proper position between C. eos and C. neogaeus on the basis of length of intestine, numbers of pharyngeal teeth, and numbers of lateral scale rows (Table 14).

Preparation of the intestine and pharyngeal teeth for examination are time-consuming processes. Also, the dissections involved leave specimens in a condition such that subsequent examination is difficult. Since a fellow graduate student, Mr. Richard Stasiak, intends to study the relationships of C. eos and C. neogaeus, I dissected a minimal number of specimens and left the rest in good condition for him.

Chrosomus erythrogaster has been reported to hybridize with Campostoma anomalum (Hubbs and Bailey, 1952:143); Chrosomus neogaeus (as "Pfrille neogaeus", Hubbs and Brown, 1929:27); Clinostomus elongatus (as "Redside dace", Trautman, 1957:326); Clinostomus funduloides (as "Rosy dace", Trautman, loc. cit.); Notropis cornutus (Cross and Minckley, 1960:4; Minckley, 1959:431; Trautman, loc. cit.); and Semotilus atromaculatus (Cross and Minckley, op. cit.:7).

Because the hybrids of "C. erythrogaster" x C. neogaeus ("Pfrille neogaeus") mentioned by Hubbs and

TABLE 14. Comparison of certain body proportions of *Chrosomus eos*, *C. neogaeus*, and their hybrids, based on specimens collected in the Cascade River, Cook County, Minnesota, on 9 September 1941 (University of Minnesota Collection No. 13289). Meristic counts are included. Ratios are expressed in thousandths of Standard Length.

Character	*C. eos* (3 ♀♀)	Hybrid, generation undetermined (1 ♀)	F_1 hybrid (1 ♀)	*C. neogaeus* (1 ♀)
Mean Standard l.	42.3 mm (41.7-43.5)	41.8 mm	44.5 mm	44.8 mm
Mean intestine length	71 mm (68-76)	52 mm	55 mm	39 mm
Mean Intestine l. / Standard l.	1688 (1563-1823)	1244	1235	871
Mean lateral scale rows	84 (81-87)	84	83	87
Pharyngeal teeth	2 with 0,5-4-0, 1 with 0,4-4,0	0,5-5,0	1,5-4,0	2,5-4,2

Brown (loc. cit.) were taken in Ontario, it is suspected that these may be C. eos x C. neogaeus. New (op. cit.: 147) treats them as the latter combination.

Hybrids of C. erythrogaster with Notropis cornutus and Dionda nubila were found in the present study.

Two specimens of C. erythrogaster x N. cornutus were taken in the headwaters of the Zumbro River, Dodge County, T105N-R16W-S9/16 (Plate 2). One was taken on 24 September 1965, the other on 20 April 1966.

Cross and Minckley reported that the heads of three specimens of C. erythrogaster x N. cornutus were more robust than the heads of the parent species. The increase in size resulted from "elongation of the postorbital region, with lesser elongation of the snout and orbit (op. cit.:4)." Increased head-size in hybrids as compared to the heads of parents has also been reported for Gila orcutti x Gila bicolor (Hubbs and Miller, 1943: 373). Hubbs and Miller thought this might be a heterotic effect.

Certain morphological features of the hybrids of C. erythrogaster x N. cornutus studied here were compared with five comparably-sized specimens of each parent species from the same locality (Table 15).

Unlike the specimens studied by Cross and Minckley, the head lengths of my hybrids were not relatively longer than those of the parent species. However, some elongation of the postorbital region of the head was

PLATE 2. Hybrid specimens of *Chrosomus erythrogaster* x *Notropis cornutus* taken in the headwaters of the Zumbro River, Dodge County, Minnesota, 24 September 1965 (specimen at top) and 20 April 1966. Photograph by Mr. Dale W. Fishbeck of the University of Minnesota.

TABLE 15. Comparison of the morphology and body proportions of two hybrids of *Chrosomus erythrogaster* x *Notropis cornutus*, collected in the headwaters of the Zumbro River, Dodge County, Minnesota, with five specimens of each parent species from the same locality. Ratios are expressed in thousandths.

Character	*C. erythrogaster* ($\bar{X}$)	Hybrid 1 (Coll. 24 Sep 1965)	Hybrid 2 (Coll. 20 Apr 1966)	*N. cornutus* ($\bar{X}$)
Sex	5 ♀♀	♂	♀	3♀♀, 2♂♂
Total length	79.3 mm	82.5 mm	79.0 mm	80.4 mm
Standard l.	64.9 mm	66.2 mm	63.1 mm	64.1 mm
Head l. / Standard l.	248	261	273	275
Orbit l. / Standard l.	059	060	067	076
Snout l. / Head l.	292	306	297	307
Upper jaw l. / Standard l.	062	074	082	087
Postorbital l. / Standard l.	116	124	125	123
Postorbital l. / Head l.	466	474	459	449
Lateral scale rows	85	62	60	43
Pharyngeal teeth	0,5-5,0	1,5-4,1	2,5-5,2	2,4-4,2
Number of anal rays	8	8	8	two with 8, 3 with 9
Length of intestine	190 mm	82 mm	94 mm	79 mm

noted along with a tendency for size of eye and length of upper jaw to lie between the corresponding dimensions in the parent species. The intestine was longer in the hybrids than the intestine in *N. cornutus*, but was closer in length to the latter than to *C. erythrogaster*.

In pigmentation, the hybrids were intermediate between *C. erythrogaster* and *N. cornutus*, as noted by Cross and Minckley (p. 6) and discussed in detail by them.

One specimen of *C. erythrogaster* x *Dionda nubila* (the Ozark minnow) was taken from Otter Creek at County Road 6, Mower County, on 24 October 1964 (Plate 3). This specimen, identified by Professor David A. Etnier, is to my knowledge the first record of a hybrid between these species. Known hybrids involving *C. erythrogaster* were listed above. *D. nubila* is known to hybridize with *Notropis pilsbryi* (Moore and Paden, 1950:92), and Hubbs (1955:11) listed in tabular form hybrids of *Dionda* with *Campostoma*, *Hybopsis*, and *Notropis* without indicating the participating species.

The hybrid was compared morphologically with five comparably-sized specimens of each parent species taken in the same collection with the hybrid (Table 16).

The head of the hybrid was proportionately longer than in either parent species, but this difference was small and perhaps due to chance variation.

The intestine was much shorter in the hybrid than

PLATE 3. Hybrid specimen of *Chrosomus erythrogaster* x *Dionda nubila* taken from Otter Creek at County Road 6, Mower County, Minnesota, 24 October 1964. Photograph by Mr. Dale W. Fishbeck of the University of Minnesota.

TABLE 16. Comparison of the morphology and body proportions of a hybrid of *Chrosomus erythrogaster* x *Dionda nubila*, taken from Otter Creek at County Road 6, Mower County, Minnesota, 24 October 1964, with five specimens of each parent species collected with the hybrid. Ratios are expressed in thousandths.

Character	*C. erythrogaster* ($\bar{X}$)	hybrid	*D. nubila* ($\bar{X}$)
Sex	3♂♂, 2♀♀	♀	2♂♂, 3♀♀
Total length	56.3 mm	56.0 mm	55.9 mm
Standard l.	45.3	45.0	44.8
Head length	11.3	11.3	10.8
Snout length	3.0	3.0	3.1
Orbit length	3.1	3.2	3.2
Postorbital length	5.2	5.0	4.6
Head l. / Standard l.	249	251	241
Orbit l. / Standard l.	068	071	071
Snout l. / Standard l.	066	067	069
Snout l. / Head l.	265	265	287
Upper jaw l. / Standard l.	060	062	065
Upper jaw l. / Head l.	239	248	269
Postorbital l. / Standard l.	115	111	103

(Table 16 continued on next page).

TABLE 16, Continued.

Character	C. erythrogaster ($\bar{X}$)	hybrid	D. nubila ($\bar{X}$)
Postorbital l. / Head l.	460	442	426
Lateral scale rows	85	49	40
Scale rows, caudal peduncle	23	15	13
Pharyngeal teeth	4 with 0,5-5,0, 1 with 0,5-5,1	0,5-4,0	0,4-4,0
Length of intestine	80 mm	61 mm	78 mm

in the specimens of either parent species examined. It measured 61 mm in the hybrid and averaged 80 mm in the *C. erythrogaster* and 78 mm in the *D. nubila*.

The scales of the hybrid were smaller than in *D. nubila*, but in size and numbers resembled those of this species more than those of *C. erythrogaster*. The scales of the Ozark minnow, especially those above the lateral stripe, are each lightest in color anteriorly and contain black pigment that is most intense along the posterior scale margin. Similar coloration was apparent in the hybrid but was less developed. The peritoneum, black in both parent species, was black in the hybrid also.

The lateral line is complete in *D. nubila*. It is incomplete in *C. erythrogaster*, typically extending half the distance from the rear of the head to the tail. It is nearly complete in the hybrid, with only the five posteriormost lateral line scales unpored.

Other hybrids involving *Chrosomus* are *C. eos* x *Notropis cornutus* (Gilbert, 1964:103), *C. oreas* x *N. cornutus* (Raney, 1950:167), and *C. oreas* x *N. cerasinus* (Raney and Lachner, 1946:226).

DIET

The Digestive Tract.

The mouth of *Chrosomus erythrogaster* is small but effective for grazing. Captive specimens were able to remove minute algal growths from glass walls of an aquarium. The pharyngeal teeth are well developed; the largest teeth often bear rudimentary terminal hooks. The teeth are typically borne in a single row on each pharyngeal arch. Of 50 sets of pharyngeal teeth examined 32 were 0,5-5,0, 16 were 0,4-5,0, and two were 0,5-5,1.

The esophagus is, according to Al-Hussaini (1949: 129), the portion of the alimentary tract between the pharyngeal arches and the point at which the intestine begins. The esophagus-intestine juncture, located directly posterior to the pharyngeal arches, is marked by a "pyloric sphincter (*loc. cit.*)." The wall of the intestine bears a reticulated design of muscle fibers.

The digestive tract is long and increases in length with age at a rate faster than the body (Table 17). As in certain other minnows (Breder and Crawford, 1922:314), the intestine of *C. erythrogaster* runs posteriorly, turns forward, then runs backward to the anus. However, it is so long in *C. erythrogaster* that the course it takes is necessarily somewhat modified: At each point where the intestine changes direction, a side loop, which gives the intestine a coiled appearance, occurs.

TABLE 17. Lengths of intestines of specimens of *Chrosomus erythrogaster* collected in the headwaters of the Zumbro River, Dodge County, Minnesota, 19 May 1965. Measurements are in millimeters.

Size interval (total lengths)	Number of specimens	Mean total length of fish	Mean length digestive tract	Ratio digestive tract: total length
20-29.9	1	29.1	38	1.31:1
30-39.9	10	36.7	66.5	1.81:1
40-49.9	10	44.4	96	2.16:1
50-59.9	10	55.2	127	2.30:1
60-69.9	10	64.8	161	2.49:1
70-80	10	74.0	189.5	2.55:1

One reason for using the anterior, middle, and posterior 20-mm portions of the intestine in analyzing diets was to determine, if possible, where digestion occurred. No assay of enzyme activity was attempted, but inspection of food items in various parts of the intestine indicated that digestion took place in all regions. Barrington (1957:126-45) discussed digestion in fishes and summarized pertinent literature.

Composition of Diet.

Microscopic plants ("algae") of the Divisions Cyanophyta, Chrysophyta, Euglenophyta, and Chlorophyta were apparently the most important food items consumed by the *C. erythrogaster* studied here.

CYANOPHYTA: Blue-green algae apparently contributed little to the sustenance of the fishes studied here (cf. Kidd, 1927:87).

Gomphosphaeria and *Oscillatoria* were the forms of blue-green algae found most commonly in the diet. *Gomphosphaeria* grew as spherical colonies and as flattened epiphytic aggregations of cells, and was consumed most often in the latter form. Morphological observations indicated near indigestibility.

Oscillatoria also seemed generally indigestible. A few cells with shrunken contents were noted, perhaps from digestive activity. 49.4% of all algal organisms counted in *C. erythrogaster* collected on 21 August 1966 were strands of <u>Oscillatoria</u>. <u>Chroococcus</u> and <u>Merismopedia</u>, both apparently indigestible, were present in most 1966 samples but sparsely so. Sizeable portions of plate-like colonies of <u>Merismopedia</u> were noted. An identifiable strand of <u>Anabaena</u> (showing a heterocyst) was seen but once, in a <u>C. erythrogaster</u> taken on 26 June.

CHRYSOPHYTA: Classes of yellow-green algae noted were the Chrysophyceae and Bacillariophyceae. The only form referable to the Chrysophyceae was a rarely-seen organism, not positively identified to genus, that had siliceous scales resembling those of <u>Mallomonas</u>. The specimens seen were in a contracted, or rounded, condition. They were found in samples taken on 4 May, 4 June, and 24 July.

Diatoms of the Class Bacillariophyceae were the most numerous organisms found in the diet. Eight of the 10 most common algal genera consumed were diatoms (Tables 18 and 19).

The diatom <u>Navicula</u> was the most abundant genus found in the diet. Although comparatively small, members of this genus contributed significantly to the diet through their presence in large numbers throughout the season and their ease of digestion. <u>Nitzschia</u> was also common throughout the study period and was likewise apparently easy to digest. Some of the largest diatoms noted belonged to this genus (e.g., <u>N. sigma</u> and <u>N.</u>

TABLE 18. Kinds of organisms found in digestive tracts of *Chrosomus erythrogaster* taken in the headwaters of the Zumbro River, Dodge County, Minnesota, in 1966. 500 identifiable dietary items were counted in each digestive tract (see text). All percentages are rounded to the nearest 0.1%.

Date	20 APR
Number of fish examined	6
Mean total length of fish (mm)	72.1

		TOTAL	MEAN PER FISH	%	
	DIVISION CYANOPHYTA				
	Class CYANOPHYCEAE				
1	Chroococcus (including C. turgidus)	1	0.17	*	1
2	Gomphosphaeria	330	55.00	11.0	2
3	Merismopedia (incl. M. glauca)	1	0.17	*	3
4	Anabaena				4
5	Oscillatoria (incl. O. limosa, O. princeps)	15	2.50	0.5	5
	DIVISION CHRYSOPHYTA				
	Class CHRYSOPHYCEAE				
6	"Rounded Mallomonas-like form"				6
	Class BACILLARIOPHYCEAE				
7	Cyclotella (incl. C. Meneghiniana)	707	117.83	23.6	7
8	Melosira (incl. M. granulata, M. varians)	1	0.17	*	8
9	Stephanodiscus				9
10	Achnanthes				10
11	Amphora (incl. A. ovalis)	5	0.83	0.2	11
12	Caloneis (incl. C. amphisbaena, C. Lewisii, C. silicula)	18	3.00	0.6	12
13	Ceratoneis	1	0.17	*	13
14	Cocconeis				14
15	Cymatopleura (incl. C. elliptica)				15
16	Cymbella (incl. C. tumida, C. ventricosa)	2	0.33	0.1	16
17	Epithemia				17
18	Eunotia				18
19	Fragilaria (incl. F. capucina, F. crotonensis)	2	0.33	0.1	19
20	?Frustulia (tentative ident. by Colingsworth)				20
21	Gomphoneis				21
22	Gomphonema (incl. G. acuminatum, G. constrictum, G. olivaceum)	793	132.17	26.4	22
23	Gyrosigma (incl. G. attenuatum)				23
24	Hantzschia				24
25	Meridion				25
26	Navicula (incl. N. crypocephala, N. dicephala, N. lanceolata, N. Petersenii, N. rhynchocephala)	694	115.67	23.1	26
27	?Neidium				27
28	Nitzschia (incl. N. acicularis, N. palea, N. sigma, N. sigmoidea)	257	42.83	8.6	28
29	Pinnularia (incl. P. interrupta)	29	4.83	1.0	29
30	?Pleurosigma				30
31	Rhoicosphenia curvata	1	0.17	*	31
32	Rhopalodia				32
33	Stauroneis (incl. S. anceps, S. parvula, S. Smithii)	4	0.67	0.1	33
34	Surirella ovalis	35	5.83	1.2	34
35	Surirella sp. (incl. S. constricta, S. linearis)	10	1.67	0.3	35
36	Synedra (incl. S. acus, S. ulna)	86	14.33	2.9	36
37	Tabellaria				37
	DIVISION EUGLENOPHYTA				
	Class EUGLENOPHYCEAE				
38	Euglena (incl. E. oxyuris, E. Spirogyra)	2	0.33	0.1	38
39	Phacus (incl. P. longicauda, P. pleuronectes, P. Spirogyra)				39
40	Trachelomonas				40
41	"Rounded euglenoid"				41
	DIVISION CHLOROPHYTA				
	Class CHLOROPHYCEAE				
42	?Eudorina				42
43	Hormidium				43
44	Oedogonium				44
45	Cladophora				45
46	Crucigenia tetrapedia	1	0.17	*	46
47	Scenedesmus				47
48	?Selenastrum	1	0.17	*	48
49	Cosmarium (incl. C. subcrenatum)	1	0.17	*	49
50	Closterium (incl. C. acutum, C. Ehrenbergii, C. Leibleinii, C. lineare)	1	0.17	*	50
51	Spirogyra				51
52	Staurastrum (incl. S. brevispinum)				52
53	"Chlorophyta -- colony"	2	0.33	0.1	53
54	"Chlorophyta -- filament"				54

*(Less than 0.1%)

	4 MAY 10 64.6			21 MAY 5 60.4			4 JUN 10 59.4			
	TOTAL	MEAN PER FISH	%	TOTAL	MEAN PER FISH	%	TOTAL	MEAN PER FISH	%	
1				3	0.6	0.1	2	0.2	*	1
2	322	32.2	6.4	338	67.6	13.5	126	12.6	2.5	2
3				3	0.6	0.1	25	2.5	0.5	3
4										4
5	15	1.5	0.3	68	13.6	2.7	317	31.7	6.3	5
6	1	0.1	*				2	0.2	*	6
7	485	48.5	9.7	339	67.8	13.6	553	55.3	11.1	7
8	5	0.5	0.1	7	1.4	0.3	3	0.3	0.1	8
9	29	2.9	0.6				6	0.6	0.1	9
10	4	0.4	0.1	18	3.6	0.7	39	3.9	0.8	10
11	14	1.4	0.3	8	1.6	0.3	89	8.9	1.8	11
12	33	3.3	0.7	32	6.4	1.3	48	4.8	1.0	12
13				1	0.2	*				13
14	5	0.5	0.1				3	0.3	0.1	14
15							2	0.2	*	15
16	4	0.4	0.1	8	1.6	0.3	17	1.7	0.3	16
17							1	0.1	*	17
18	1	0.1	*							18
19	10	1.0	0.2	13	2.6	0.5	6	0.6	0.1	19
20										20
21										21
22	124	12.4	2.5	120	24.0	4.8	47	4.7	0.9	22
23	3	0.3	0.1				2	0.2	*	23
24	1	0.1	*							24
25										25
26	1141	114.1	22.8	672	134.4	26.9	2177	217.7	43.5	26
27										27
28	1656	165.6	33.1	642	128.4	25.7	952	95.2	19.0	28
29	19	1.9	0.4	20	4.0	0.8	467	46.7	9.3	29
30										30
31	1	0.1	*				2	0.2	*	31
32							1	0.1	*	32
33	8	0.8	0.2				3	0.3	0.1	33
34	874	87.4	17.5	18	3.6	0.7	8	0.8	0.2	34
35	20	2.0	0.4	13	2.6	0.5	16	1.6	0.3	35
36	208	20.8	4.2	158	31.6	6.3	56	5.6	1.1	36
37				1	0.2	*				37
38							6	0.6	0.1	38
39	5	0.5	0.1				5	0.5	0.1	39
40							2	0.2	*	40
41	6	0.6	0.1	12	2.4	0.5	7	0.7	0.1	41
42										42
43	1	0.1	*							43
44				1	0.2	*				44
45							2	0.2	*	45
46										46
47										47
48										48
49	1	0.1	*							49
50	3	0.3	0.1	3	0.6	0.1	8	0.8	0.2	50
51				2	0.4	0.1				51
52	1	0.1	*							52
53										53
54										54

	26 JUN 10 68.6			24 JUL 10 65.4			21 AUG 10 72.1			
	TOTAL	MEAN PER FISH	%	TOTAL	MEAN PER FISH	%	TOTAL	MEAN PER FISH	%	
1	2	0.2	*	17	1.7	0.3	7	0.7	0.1	1
2	448	44.8	9.0	383	38.3	7.7	164	16.4	3.3	2
3	5	0.5	0.1	23	2.3	0.5	23	2.3	0.5	3
4	1	0.1	*							4
5	135	13.5	2.7	341	34.1	6.8	2470	247.0	49.4	5
6				2	0.2	*				6
7	954	95.4	19.1	602	60.2	12.0	545	54.5	10.9	7
8				1	0.1	*	2	0.2	*	8
9	4	0.4	0.1	1	0.1	*	2	0.2	*	9
10	29	2.9	0.6	46	4.6	0.9	29	2.9	0.6	10
11	194	19.4	3.9	730	73.0	14.6	304	30.4	6.1	11
12	135	13.5	2.7	1050	105.0	21.0	155	15.5	3.1	12
13										13
14	9	0.9	0.2	9	0.9	0.2	19	1.9	0.4	14
15	1	0.1	*	1	0.1	*	6	0.6	0.1	15
16	11	1.1	0.2	11	1.1	0.2	9	0.9	0.2	16
17				6	0.6	0.1	2	0.2	*	17
18							2	0.2	*	18
19				1	0.1	*	2	0.2	*	19
20				1	0.1	*				20
21										21
22	76	7.6	1.5	26	2.6	0.5	28	2.8	0.6	22
23	13	1.3	0.3	28	2.8	0.6	20	2.0	0.4	23
24										24
25										25
26	1367	136.7	27.3	889	88.9	17.8	553	55.3	11.1	26
27										27
28	693	69.3	13.9	529	52.9	10.6	380	38.0	7.6	28
29	573	57.3	11.5	144	14.4	2.9	104	10.4	2.1	29
30				1	0.1	*				30
31	6	0.6	0.1	1	0.1	*	2	0.2	*	31
32							1	0.2	*	32
33	6	0.6	0.1	10	1.0	0.2	2	0.2	*	33
34	31	3.1	0.6	4	0.4	0.1	9	0.9	0.2	34
35	180	18.0	3.6	29	2.9	0.6	37	3.7	0.7	35
36	53	5.3	1.1	18	1.8	0.4	19	1.9	0.4	36
37										37
38	18	1.8	0.4	4	0.4	0.1	10	1.0	0.2	38
39	20	2.0	0.4	30	3.0	0.6	50	5.0	1.0	39
40	1	0.1	*	20	2.0	0.4	20	2.0	0.4	40
41	31	3.1	0.6	34	3.4	0.7	19	1.9	0.4	41
42	1	0.1	*	1	0.1	*				42
43										43
44										44
45				2	0.2	*				45
46										46
47				1	0.1	*				47
48										48
49				1	0.1	*				49
50	3	0.3	0.1	3	0.3	0.1	1	0.1	*	50
51										51
52										52
53							3	0.3	0.1	53
54							1	0.1	*	54

	25 SEP 10 65.3			12 OCT 10 66.1			12 NOV. 6 58.7			
	TOTAL	MEAN PER FISH	%	TOTAL	MEAN PER FISH	%	TOTAL	MEAN PER FISH	%	
1	5	0.5	0.1	2	0.2	*				1
2	577	57.7	11.5	386	38.6	7.7	278	46.33	9.3	2
3	25	2.5	0.5	11	1.1	0.2	1	0.17	*	3
4										4
5	893	89.3	17.9	106	10.6	2.1	13	2.17	0.4	5
6										6
7	1239	123.9	24.8	1315	131.5	26.3	442	73.67	14.7	7
8	2	0.2	*	5	0.5	0.1				8
9				6	0.6	0.1				9
10	19	1.9	0.4	48	4.8	1.0	8	1.33	0.3	10
11	673	67.3	13.5	568	56.8	11.4	337	56.17	11.2	11
12	54	5.4	1.1	90	9.0	1.8	42	7.00	1.4	12
13										13
14	15	1.5	0.3	75	7.5	1.5	8	1.33	0.3	14
15	10	1.0	0.2	9	0.9	0.2	3	0.50	0.1	15
16	9	0.9	0.2	18	1.8	0.4	131	21.83	4.4	16
17	3	0.3	0.1							17
18	2	0.2	*	11	1.1	0.2	4	0.67	0.1	18
19				3	0.3	0.1				19
20										20
21				2	0.2	*				21
22	56	5.6	1.1	56	5.6	1.1	300	50.00	10.0	22
23	29	2.9	0.6	29	2.9	0.6	11	1.83	0.4	23
24										24
25				1	0.1	*				25
26	683	68.3	13.7	1094	109.4	21.9	548	91.33	18.3	26
27				1	0.1	*				27
28	485	48.5	9.7	799	79.9	16.0	687	114.5	22.9	28
29	79	7.9	1.6	164	16.4	3.3	27	4.5	0.9	29
30										30
31	8	0.8	0.2	20	2.0	0.4	1	0.2	*	31
32										32
33	10	1.0	0.2	6	0.6	0.1	5	0.83	0.2	33
34	1	0.1	*	10	1.0	0.2	70	11.67	2.3	34
35	46	4.6	0.9	60	6.0	1.2	16	2.67	0.5	35
36	6	0.6	0.1	39	3.9	0.8	55	9.17	1.8	36
37	1	0.1	*	1	0.1	*				37
38	6	0.6	0.1	9	0.9	0.2	3	0.50	0.1	38
39	17	1.7	0.3	18	1.8	0.4	4	0.67	0.1	39
40	7	0.7	0.1	8	0.8	0.2	3	0.50	0.1	40
41	28	2.8	0.6	23	2.3	0.5	1	0.17	*	41
42										42
43										43
44				1	0.1	*				44
45	3	0.3	0.1	1	0.1	*				45
46										46
47										47
48										48
49										49
50	3	0.3	0.1	1	0.1	*				50
51										51
52										52
53	6	0.6	0.1	3	0.3	0.1				53
54				1	0.1	*	2	0.33	0.1	54

GRAND TOTAL
87
64.9

	TOTAL	MEAN PER FISH	%
1	39	0.45	0.1
2	3352	38.53	7.7
3	117	1.35	0.3
4	1	0.01	*
5	4373	50.26	10.1
6	5	0.06	*
7	7181	82.54	16.5
8	26	0.30	0.1
9	48	0.55	0.1
10	240	2.76	0.6
11	2922	33.59	6.7
12	1657	19.05	3.8
13	2	0.02	*
14	143	1.64	0.3
15	32	0.37	0.1
16	220	2.53	0.5
17	12	0.14	*
18	20	0.23	*
19	37	0.43	0.1
20	1	0.01	*
21	2	0.02	*
22	1626	18.69	3.7
23	135	1.55	0.3
24	1	0.01	*
25	1	0.01	*
26	9818	112.85	22.6
27	1	0.1	*
28	7080	81.38	16.3
29	1626	18.69	3.7
30	1	0.01	*
31	42	0.48	0.1
32	2	0.02	*
33	54	0.62	0.1
34	1060	12.18	2.4
35	427	4.91	1.0
36	698	8.02	1.6
37	3	0.03	*
38	58	0.67	0.1
39	149	1.71	0.3
40	61	0.70	0.1
41	161	1.85	0.4
42	2	0.02	*
43	1	0.01	*
44	2	0.02	*
45	8	0.09	*
46	1	0.01	*
47	1	0.01	*
48	1	0.01	*
49	3	0.03	*
50	26	0.30	0.1
51	2	0.02	*
52	1	0.01	*
53	14	0.16	*
54	4	0.05	*

OTHER ITEMS SEEN:

Shreds of vascular plants -- all samples.

Spores -- all samples.

Seeds -- 25 Sept, 12 Oct.

Rotifers -- 20 Apr, 4 Jun, 26 Jun.

Arthropods (incl. Crustacea and Insecta) -- 4 Jun, 25 Sept, 12 Oct, 12 Nov.

Protozoa (Difflugia) -- 24 Jul.

TABLE 19. The 10 most numerous kinds of algae found in the diet of *Chrosomus erythrogaster* from the headwaters of the Zumbro River, Dodge County, Minnesota, in 1966.

Genus	Percentage of diet formed according to numbers present
Navicula	22.6
Cyclotella[1]	16.5
Nitzschia	16.3
Oscillatoria[1, 2]	10.1
Gomphosphaeria[1, 2]	7.7
Amphora	6.7
Caloneis	3.8
Gomphonema	3.7
Pinnularia	3.7
Surirella	3.4
TOTAL	94.5

[1]Indigestible forms.

[2]*Oscillatoria* and *Gomphosphaeria* are blue-green algae (Division Cyanophyta). The other genera are diatoms (Division Chrysophyta: Class Bacillariophyceae).

sigmoidea). *Amphora* appeared to be rare in the diet of *C. erythrogaster* until mid-June, but increased greatly thereafter. Large and seemingly easy to digest, *Amphora* (chiefly *A. ovalis*) appeared to be an important food item from July to November.

Some diatoms, such as *Caloneis* and *Pinnularia*, were at their peak of abundance in the diet in summer. Genera such as *Gomphonema* and *Synedra* were more common in April and May than in later months. 874 of the 894 *Surirella* noted in the 4 May sample were *S. ovalis*, a conspicuous peak of dietary abundance for this species.

The Genus *Cyclotella* was second numerically only to *Navicula* in the diet, but was apparently of little nutritional value. *C. Meneghiniana* was well-digested when seen, but more than 99 percent of the *Cyclotella* noted were of a small species, not identified, that seemed indigestible. This tiny diatom tended to linger in the alimentary tract longer than did larger, digestible forms. Thus, when the anterior part of the intestine was relatively empty, numbers of *Cyclotella* (and other indigestible forms, especially *Gomphosphaeria*) were often comparatively higher than toward the rear where the bulk of the contents were located. This might merely indicate ingestion of these forms after other algae were consumed, but does suggest some retardation in the movement of certain indigestible items through the intestine.

Large diatoms, especially long and slim ones, were often fragmented. It seems unlikely that special efforts were exerted to break them open, for intact diatoms were digested equally well. Enzymes apparently pass through openings (e.g., raphes, punctae) in diatom frustules (cf. Fish, 1951:901). Diatoms incurring breakage perhaps did so while being buffeted after they were swallowed.

EUGLENOPHYTA: Genera of this Division noted were *Euglena*, *Phacus*, and *Trachelomonas*. Unidentified rounded individuals, some possibly of other genera, were also seen.

Although never abundant, euglenoids were present in the diet in some numbers in summer. *Phacus* seemed most easily digested among them, usually exhibiting the loss of at least some cell contents. The other forms, although often shrunken or rounded, were poorly digested. Cells of *Euglena oxyuris* var. *minor* were intact and apparently undigested when seen. However, paramylon bodies looking like those of this euglenoid were twice seen floating free, indicating that it or a similar form underwent cell breakage. Cell contents of *Trachelomonas* were usually shrunken and rounded, retaining a light green color.

CHLOROPHYTA: Green algae were rarely found in stream specimens of *C. erythrogaster* and, when seen, were usually poorly digested. Cells of filamentous forms such as *Cladophora* and *Oedogonium* were but slightly shrunken. Digestion of the contents of *Closterium*, the genus of "desmid" most commonly noted, ranged from unappreciable to complete.

Although green algae seemed nutritionally unimportant to *C. erythrogaster* in the stream studied, members of such genera as *Stigeoclonium* and *Spirogyra* were readily eaten in aquarium experiments. The *Stigeoclonium* was consumed voraciously and is here recommended as a food for minnows kept in captivity.

Cladophora was partially digested by *C. erythrogaster* in the aquarium, but the fishes ate it only when starved and no other food was available. Its unpalatibility was perhaps due largely to its wiry texture and thick cell walls. It was not determined if lack of feeding on *Cladophora* by fishes in the stream study area permitted its growth, but it was the only alga noted to form sizeable colonies there. *Cladophora* and certain vascular plants in the study area harbored diatoms (such as *Cymbella*, *Gomphonema*, *Navicula*, *Nitzschia*, *Pinnularia*, and *Synedra*) that were eaten by *C. erythrogaster*, and could have been incidentally ingested with the diatoms. A germling *Cladophora* was identified by Mr. Alden E. Hine in a redbelly dace taken 12 October, indicating that this alga reproduces in the stream in autumn.

Selection of Diet.

The diet of freshwater fishes in relation to availability of food and the presence of other fishes that could compete for food has been discussed by many workers (see, for example, Boesel, 1938; Clark, 1943; Dinsmore, 1962; Forbes, 1878, 1880, 1880a, 1888, 1888a; Hartley, 1948; Kraatz, 1923, 1928; Lewis *et al*, 1961; and others).

Forbes (1914) stated that freshwater fishes have available a common body of miscellaneous food resources, upon which many of them feed indiscriminately according to immediate circumstances, while (p. 4)

> "... there is a tendency to specialize in various directions, which tendency goes to its limit in some species, halts at various intermediate stages in others, and in still others is hardly discernable at all."

Larkin (1956) reviewed literature on dietary interrelationships of freshwater fishes and concluded that they are as a rule flexible and adaptable in their diet. He stated that freshwater environments "offer little opportunity for specialization (p. 339)" so that fishes share many resources, including food, with other species.

C. erythrogaster apparently fed mostly from bottom sediments in the stream studied here. It was conservatively estimated that 90 percent of the material in a typical intestine was detritus, sand, and silt.

Since most of the material consumed was debris and a sizeable part of the "food" (such as blue-green algae) seemed indigestible, nutritionally useful algal items formed but a small percentage, volume-wise, of the gut contents.

Little or no food selectivity was demonstrated, as indicated by the variety of organisms consumed, the agreement of kinds of algae eaten with the kinds common in the stream, and the consumption of indigestible materials. Detailed counts of plankton sampled in the study area in 1966 were not made, but genera found in plankton samples seemed to correspond to those eaten by redbelly dace taken on the same day (Table 20). Seasonal variations in numbers of the kinds of algae present were reflected in the diet, as has been shown for other algae-eating minnows (Griffith and Voorhees, 1960:314). Tychoplankton seemed common in the study area with such typically-sessile diatoms as Amphora and Gomphonema present. Bottom-feeding fishes may ingest plankton when water is taken in during respiration (Coyle, 1930:25).

Chantransia sp. (Rhodophyta: Rhodophyceae) was the only alga present in the stream samples that was not found in the diet of redbelly dace collected in 1966. Chantransia sp. (identified by Dr. Brook) was taken in a plankton tow on 21 May. The absence of this freshwater "red" alga from the diet may be related to

TABLE 20. Comparison of algae found in the diet of <u>Chrosomus erythrogaster</u> with algae found in the environment in the headwaters of the Zumbro River, Dodge County, on (A) 21 May, (B) 24 July, and (C) 25 September 1966.

(A) 21 May

Genera	Presence (X) or absence in: Digestive tracts	Plankton	Epiphytes and epiliths
Chroococcus	X		
Gomphosphaeria	X		
Merismopedia	X	X	
Oscillatoria	X	X	
Chantransia		X	
Amphora	X		
Caloneis	X		
Ceratoneis	X		
Cocconeis			X
Cyclotella	X		X
Cymbella	X	X	X
Fragilaria	X	X	X
Gomphonema	X		X
Melosira	X	X	X
Navicula	X	X	X
Nitzschia	X	X	X
Pinnularia	X	X	
Surirella	X		
Synedra	X		X
Tabellaria	X		
Euglena			X
Trachelomonas			X
Cladophora			X
Closterium	X	X	X
Oedogonium	X		
Spirogyra	X		

TABLE 20, Continued.

(B) 24 July

Genera	Presence (X) or absence in: Digestive tracts	Plankton	Epiphytes and epiliths
Chroococcus	X		
Gomphosphaeria	X	X	X
Merismopedia	X		
Oscillatoria	X	X	
Achnanthes	X	X	
Amphora	X	X	X
Caloneis	X	X	
Cocconeis	X		X
Cyclotella	X	X	X
Cymbella	X	X	X
Epithemia	X		
Eunotia	X		X
Fragilaria	X	X	
Gomphonema	X		X
Gyrosigma	X	X	
Melosira	X		
Navicula	X	X	X
Nitzschia	X	X	X
Pinnularia	X		X
Rhoicosphenia	X		
Stauroneis	X	X	
Stephanodiscus	X		
Surirella	X		
Synedra	X		X
Euglena	X		X
Phacus	X		X
Trachelomonas	X		X
Cladophora	X		X
Closterium		X	X
Cosmarium	X		
Selenastrum			X

TABLE 20, Continued.

(C) 25 September

Genera	Digestive tracts	Plankton	Epiphytes and epiliths
	Presence (X) or absence in:		
Chroococcus	X		
Gomphosphaeria	X	X	X
Merismopedia	X	X	
Oscillatoria	X		X
Achnanthes	X		
Amphora	X	X	X
Caloneis	X	X	
Cocconeis	X		X
Cyclotella	X		X
Cymatopleura	X		
Cymbella	X	X	X
Epithemia	X		
Eunotia	X		
Fragilaria		X	X
Gomphonema	X	X	X
Gyrosigma	X	X	
Melosira	X		
Navicula	X	X	X
Nitzschia	X	X	X
Pinnularia	X		
Rhoicosphenia	X		X
Stauroneis	X		
Surirella	X	X	
Synedra	X	X	X
Euglena	X		X
Phacus	X		X
Trachelomonas	X		
Cladophora	X		X
Closterium	X	X	
Oedogonium			X

its apparent rarity in the stream. It is known to be eaten by minnows (Frost, 1943:149).

Opportunism in selection of food by C. erythrogaster is well-documented. In a pond at Old Forge, New York, this species fed primarily on algae, the water weed Potamogeton sp., and the water lily Nymphaea advena, all of which were locally common (Needham, 1908:180-1). Ferguson (in Needham, op. cit.) examined "stomachs" of 92 C. erythrogaster taken from 25 April through 6 June 1904 in Pettibone Creek in Illinois. Here algae and silt were predominantly eaten at first, but when invertebrates appeared in substantial numbers, the latter assumed dietary prominence. The insect Chironomus was the invertebrate consumed most commonly, but earthworms, nonaquatic beetles, entomostracans, ants, and a mayfly nymph were also found (p. 187).

Invertebrates were rare in the natural diet of the C. erythrogaster studied here, being represented by a few arthropods and rotifers. The arthropods were digested, whereas the rotifers, probably swallowed incidentally, were not.

Numbers of invertebrates in the study area were not determined, but intestines of five specimens each of the minnows Semotilus atromaculatus and Notropis cornutus contained both adult and immature insects. Larger than C. erythrogaster, these species could, with other omnivorous fishes in the stream (such as the minnow *Campostoma anomalum* and the sunfish *Lepomis cyanellus*), conceivably limit the invertebrates available to *C. erythrogaster*.

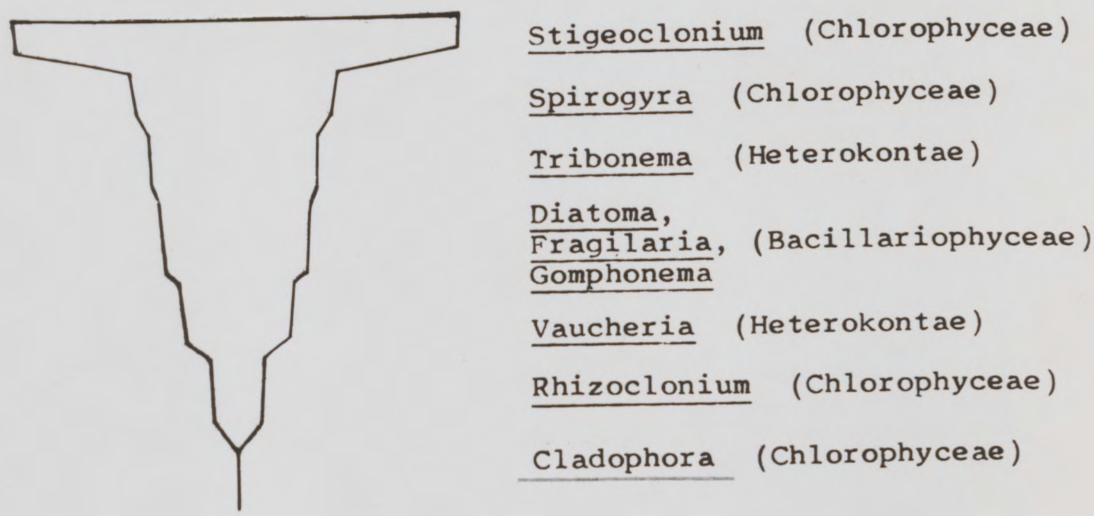
In a laboratory study of food preferences, nine genera of algae (three diatoms, two heterokonts, and four chlorophytes) were offered in various combinations of two or three at a time to redbelly dace taken from the study area. Observations on relative rates of consumption showed that the "succulent" chlorophyte *Stigeoclonium* was eaten at least twice as rapidly as any other alga tested (Fig. 5).

Feeding Behavior.

Forbes and Richardson (1920:113) found that food of *C. erythrogaster* was "evidently obtained by nibbling or sucking the surface slime from stones and other objects on the bottom." My observations coincide with theirs. Ferguson (*in* Needham, 1908:188) observed *C. erythrogaster* feeding on "midges" of the insect Family Chironomidae and stated that although the dace usually did not feed until midges touched the surface, they often leaped out of the water to catch this prey.

Ferguson (*loc. cit.*) fed midge larvae to five specimens of *C. erythrogaster* in an aquarium for 22 days, noting that the two "full grown" dace ate an average of 25 larvae each day, while the three "half grown" individuals averaged 11. I have seen *C.*

FIG. 5. Comparison of rates of consumption of nine genera of algae by *Chrosomus erythrogaster* in an aquarium. The diagram indicates relative degrees of acceptance; *Stigeoclonium*, for example, is shown to be eaten at least twice as rapidly as any other alga tested.


Stigeoclonium (Chlorophyceae)
Spirogyra (Chlorophyceae)
Tribonema (Heterokontae)
Diatoma, Fragilaria, Gomphonema (Bacillariophyceae)
Vaucheria (Heterokontae)
Rhizoclonium (Chlorophyceae)
Cladophora (Chlorophyceae)

erythrogaster pursue and capture *Gammarus* sp. (Crustacea: Amphipoda) in an aquarium.

Daily Cycle of Activity.

At 4-hour intervals from 9:30 pm, 15 May, through 5:30 pm, 16 May, 1967, samples of *C. erythrogaster* were collected in the study area. The diets of ten specimens from each sample were examined (Table 21). The composition of plankton samples taken each time dace were captured was also determined (Table 22). A sample of epiphytes, taken from rotting vegetation, was analyzed as well (Table 22).

Four algal genera found in plankton collected in the 20-hour study period, *Asterionella* (Bacillariophyceae), *Ceratium* (Dinophyceae), *Pediastrum*, and *Volvox* (both Chlorophyceae), had not been noted in the stream previously. They were not found, on this or any other occasion, in intestines of *C. erythrogaster*. Two diatom genera, *Amphipleura* and *Diatoma*, were noted in the diet for the first time.

Numbers of many organisms eaten by redbelly dace appeared to fluctuate during the 20-hour period studied, but it seems imprudent to attribute these deviations to anything beyond random variations in the diet of different individuals. The kinds of organisms found in the samples of plankton from the stream may

TABLE 21. Kinds of organisms found in intestines of *Chrosomus erythrogaster* taken in the headwaters of the Zumbro River, Dodge County, Minnesota, at 4-hour intervals from 9:30 pm, 15 May, through 5:30 pm, 16 May, 1967. 500 identifiable dietary items were counted in each intestine (see text). All percentages are rounded to the nearest 0.1%.

Time 9:30 PM
Number of fish examined 10
Mean total length of fish (mm) 64.7

	TOTAL	MEAN PER FISH	%	
DIVISION CYANOPHYTA				
Class CYANOPHYCEAE				
1 Chroococcus				1
2 Gomphosphaeria	94	9.4	1.9	2
3 Merismopedia				3
4 Oscillatoria	38	3.8	0.8	4
DIVISION CHRYSOPHYTA				
Class CHRYSOPHYCEAE				
5 "Rounded Mallomonas-like form"				5
Class BACILLARIOPHYCEAE				
6 Cyclotella	428	42.8	8.6	6
7 Melosira	7	0.7	0.1	7
8 Stephanodiscus	19	1.9	0.4	8
9 Achnanthes	54	5.4	1.1	9
10 Amphipleura				10
11 Amphora	27	2.7	0.5	11
12 Caloneis	35	3.5	0.7	12
13 Cocconeis	6	0.6	0.1	13
14 Cymatopleura	1	0.1	*	14
15 Cymbella	19	1.9	0.4	15
16 Diatoma				16
17 Epithemia				17
18 Eunotia	2	0.2	*	18
19 Fragilaria	16	1.6	0.3	19
20 Gomphonema	228	22.8	4.6	20
21 Gyrosigma	9	0.9	0.2	21
22 Meridion				22
23 Navicula	1842	184.2	36.8	23
24 Nitzschia	883	88.3	17.7	24
25 Pinnularia	55	5.5	1.1	25
26 ?Pleurosigma				26
27 Rhoicosphenia				27
28 Stauroneis	16	1.6	0.3	28
29 Surirella ovalis	415	41.5	8.3	29
30 Surirella sp.	32	3.2	0.6	30
31 Synedra	741	74.1	14.8	31
DIVISION EUGLENOPHYTA				
Class EUGLENOPHYCEAE				
32 Euglena	1	0.1	*	32
33 Phacus	6	0.6	0.1	33
34 "Rounded euglenoid"	21	2.1	0.4	34
DIVISION CHLOROPHYTA				
Class CHLOROPHYCEAE				
35 ?Eudorina	1	0.1	*	35
36 Cladophora	2	0.2	*	36
37 Cosmarium				37
38 Closterium				38
39 "Chlorophyta -- colony"	1	0.1	*	39
40 "Chlorophyta -- filament"	1	0.1	*	40

* (Less than 0.1%)

	1:30 AM 10 67.4			5:30 AM 10 60.9			9:30 AM 10 66.1			
	TOTAL	MEAN PER FISH	%	TOTAL	MEAN PER FISH	%	TOTAL	MEAN PER FISH	%	
1				1	0.1	*				1
2	139	13.9	2.8	131	13.1	2.6	83	8.3	1.7	2
3										3
4	9	0.9	0.2	34	3.4	0.7	41	4.1	0.8	4
5				8	0.8	0.2	7	0.7	0.1	5
6	412	41.2	8.2	562	56.2	11.2	187	18.7	3.7	6
7	27	2.7	0.5	17	1.7	0.3	2	0.2	*	7
8	51	5.1	1.0	26	2.6	0.5	11	1.1	0.2	8
9	35	3.5	0.7	57	5.7	1.1	17	1.7	0.3	9
10	2	0.2	*							10
11	17	1.7	0.3	20	2.0	0.4	33	3.3	0.7	11
12	22	2.2	0.4	33	3.3	0.7	57	5.7	1.1	12
13				2	0.2	*				13
14	3	0.3	0.1	1	0.1	*	1	0.1	*	14
15	25	2.5	0.5	20	2.0	0.4	4	0.4	0.1	15
16	2	0.2	*	2	0.2	*				16
17	1	0.1	*							17
18	2	0.2	*	3	0.3	0.1	1	0.1	*	18
19	71	7.1	1.4	45	4.5	0.9	7	0.7	0.1	19
20	349	34.9	7.0	238	23.8	4.8	73	7.3	1.5	20
21	6	0.6	0.1	8	0.8	0.2	6	0.6	0.1	21
22				1	0.1	*				22
23	1744	174.4	34.9	1383	138.3	27.7	1663	166.3	33.3	23
24	971	97.1	19.4	1414	141.4	28.3	1808	180.8	36.2	24
25	39	3.9	0.8	41	4.1	0.8	96	9.6	1.9	25
26										26
27										27
28	69	6.9	1.4	85	8.5	1.7	37	3.7	0.7	28
29	356	35.6	7.1	287	28.7	5.7	376	37.6	7.5	29
30	22	2.2	0.4	40	4.0	0.8	39	3.9	0.8	30
31	577	57.7	11.5	473	47.3	9.5	420	42.0	8.4	31
32										32
33	2	0.2	*	4	0.4	0.1	3	0.3	0.1	33
34	43	4.3	0.9	61	6.1	1.2	23	2.3	0.5	34
35				1	0.1	*	1	0.1	*	35
36	3	0.3	0.1				1	0.1	*	36
37							1	0.1	*	37
38							1	0.1	*	38
39										39
40	1	0.1	*	2	0.2	*	1	0.1	*	40

	1:30 PM 10 63.4			5:30 PM 10 64.8			GRAND TOTAL 60 64.6			
	TOTAL	MEAN PER FISH	%	TOTAL	MEAN PER FISH	%	TOTAL	MEAN PER FISH	%	
1							1	0.02	*	1
2	48	4.8	1.0	178	17.8	3.6	673	11.22	2.2	2
3	1	0.1	*				1	0.02	*	3
4	17	1.7	0.3	29	2.9	0.6	168	2.80	0.6	4
5	10	1.0	0.2	18	1.8	0.4	43	0.72	0.1	5
6	226	22.6	4.5	392	39.2	7.8	2207	36.80	7.4	6
7	3	0.3	0.1				56	0.93	0.2	7
8	15	1.5	0.3	16	1.6	0.3	138	2.30	0.5	8
9	25	2.5	0.5	12	1.2	0.2	200	3.33	0.7	9
10							2	0.03	*	10
11	27	2.7	0.5	14	1.4	0.3	138	2.30	0.5	11
12	53	5.3	1.1	50	5.0	1.0	250	4.17	0.8	12
13				1	0.1	*	9	0.15	*	13
14	1	0.1	*	1	0.1	*	8	0.13	*	14
15	11	1.1	0.2	7	0.7	0.1	86	1.43	0.3	15
16				1	0.1	*	5	0.08	*	16
17							1	0.02	*	17
18	2	0.2	*				10	0.17	*	18
19	5	0.5	0.1	3	0.3	0.1	147	2.45	0.5	19
20	126	12.6	2.5	62	6.2	1.2	1076	17.93	3.6	20
21	5	0.5	0.1	6	0.6	0.1	40	0.67	0.1	21
22				2	0.2	*	3	0.05	*	22
23	1812	181.2	36.2	1573	157.3	31.5	10017	166.95	33.4	23
24	1673	167.3	33.5	1645	164.5	32.9	8394	139.90	28.0	24
25	88	8.8	1.8	80	8.0	1.6	399	6.65	1.3	25
26				1	0.1	*	1	0.02	*	26
27	1	0.1	*				1	0.02	*	27
28	14	1.4	0.3	7	0.7	0.1	228	3.80	0.8	28
29	284	28.4	5.7	319	31.9	6.4	2037	33.95	6.8	29
30	27	2.7	0.5	25	2.5	0.5	185	3.08	0.6	30
31	484	48.4	9.7	526	52.6	10.5	3221	53.68	10.7	31
32							1	0.02	*	32
33	4	0.4	0.1	4	0.4	0.1	23	0.38	0.1	33
34	34	3.4	0.7	27	2.7	0.5	209	3.48	0.7	34
35							3	0.05	*	35
36	1	0.1	*				7	0.12	*	36
37							1	0.02	*	37
38							1	0.02	*	38
39	1	0.1	*				2	0.03	*	39
40	2	0.2	*	1	0.1	*	8	0.13	*	40

OTHER ITEMS SEEN: Protozoa (Difflugia); Arthropoda.

TABLE 22. Organisms found in samples of plankton taken at 4-hour intervals in the headwaters of the Zumbro River, Dodge County, Minnesota, from 9:30 pm, 15 May, through 5:30 pm, 16 May, 1967, with a comparison of the plankton to epiphytic algae collected there at 5:30 pm, 16 May. Plankton was sampled at 9:30 pm, 15 May (Sample 1), 1:30 am, 16 May (2), 5:30 am (3), 9:30 am (4), 1:30 pm (5), and 5:30 pm (6).

TABLE 22.

SAMPLE NUMBER	PLANKTON 1	2	3	4	5	6	Σ	%	EPIPHYTIC ALGAE Σ	%
Division Cyanophyta										
Gomphosphaeria[1]	0	0	2	0	0	2	4	0.27	2	0.13
Oscillatoria[1]	1	0	0	2	5	1	9	0.60	2	0.13
Division Chrysophyta										
Achnanthes	4	0	2	2	4	3	15	1.00	16	1.07
Amphora								0.00	3	0.20
Asterionella[1]	0	2	0	0	1	0	3	0.20		0.00
Caloneis	1	3	2	0	1	0	7	0.47	4	0.27
Cocconeis[2]	0	2	0	0	15	3	20	1.33		0.00
Cyclotella	2	1	1	1	3	2	10	0.67	3	0.33
Cymatopleura	2	2	1	0	0	2	7	0.47		0.00
Cymbella	1	2	0	2	0	1	6	0.40	10	0.67
Epithemia[3]	0	0	0	4	4	1	9	0.60		0.00
Eunotia	0	0	1	0	0	0	1	0.07	4	0.27
Fragilaria[1]	4	3	6	1	1	4	19	1.27	2	0.13
Gomphonema[3]	2	7	5	11	3	7	35	2.33	145	9.67
Gyrosigma	3						3	0.20	1	0.07
Melosira[1]	4	0	3	0	0	0	7	0.47	2	0.13
Navicula	59	66	73	73	99	67	437	29.13	894	59.60
Nitzschia	55	57	51	64	50	73	350	23.33	138	9.20
Pinnularia	7	12	13	3	4	3	42	2.80	37	2.47
Rhoicosphenia[2]	0	0	0	1	1	0	2	0.13		0.00
Stauroneis	4	3	2	0	1	0	10	0.67	28	1.87
Stephanodiscus	0	1	1	0	0	0	2	0.13	2	0.13
Surirella ovalis	27	21	40	21	7	15	131	8.73	123	8.20
Surirella sp.	7	9	4	4	2	3	29	1.93	3	0.20
Synedra	60	57	41	57	40	57	312	20.80	77	5.13
Tabellaria[1]			1				1	0.07		0.00

TABLE 22, Continued.

SAMPLE NUMBER	PLANKTON 1	2	3	4	5	6	Σ	%	EPIPHYTIC ALGAE Σ	%
Division Pyrrophyta										
Ceratium				1			1	0.07	0	0.00
Div. Euglenophyta										
"euglenoid"				1		1	2	0.13	2	0.13
Division Chlorophyta										
Cladophora[1]					6		6	0.40	0	0.00
Closterium				1			1	0.07	0	0.00
Cosmarium	1						1	0.07	0	0.00
Pediastrum[1]					1		1	0.07	0	0.00
Volvox[1]	1					1	2	0.13	0	0.00
"colonial chlorophyte"	4	2	0	0	0	3	9	0.60	0	0.00
"single-celled chlorophyte"	1	0	1	1	2	1	6	0.40	2	0.13
TOTAL	250	250	250	250	250	250	1500	100.01	1500	100.13
UNIDENTIFIED	31	21	18	26	36	17	149		58	

[1]Occurring as colonies/filaments. Each counted as one individual.

[2]Epiphytic on other plankton.

[3]Epiphytic on plankton and also occurring as independent individuals.

best be said to correspond in general to the kinds of organisms eaten.

The volume of food in the fishes studied varied with time of day. As with other minnows (Starrett, 1950a:220), feeding decreased at night. This could reflect general nocturnal inactivity, as documented for other species (Starrett, 1950:120). Whereas feeding activity of minnows studied by Starrett (1950a:220) seemed highest around dusk, my samples indicate that the peak for *C. erythrogaster* was around midday on the date studied (Table 23).

The samples of 15-16 May consisted mostly of males and the specimens were all between 55 and 71 mm in total length. To sacrifice large numbers of individuals in order to determine if activity patterns varied with size and sex was not within the scope of this study. However, it was clear that variation occurred, perhaps at random, in the amount of food present in fishes of the same sex and similar size that were collected together.

Effects on Algal Growth.

Feeding of *C. erythrogaster* and associated species may logically be said to limit the growth of food plants in a stream if the consumers are sufficiently numerous. An example of what effect can be wrought upon an algal biomass by minnows was illustrated by an experiment in

TABLE 23. Daily cycle of feeding activity of *Chrosomus erythrogaster* in the headwaters of the Zumbro River, Dodge County, Minnesota, according to amount of food present in 120 specimens (20 per sample) collected at 4-hour intervals from 9:30 pm, 15 May, through 5:30 pm, 16 May, 1967. Total lengths are in millimeters.

Time	Average (and range) total length of fish	PERCENT OF TOTAL VOLUME OF INTESTINE OCCUPIED										
		Empty	1-9.9	10-19.9	20-29.9	30-39.9	40-49.9	50-59.9	60-69.9	70-79.9	80-89.9	90-100
9:30 pm	64.4 (60.0-68.3)	3	3	1	1		1	1	1	4	3	2
1:30 am	64.7 (60.0-69.6)	1		3	2	1	5		6		2	
5:30 am	62.6 (55.0-71.0)	6	3	1	4	2	2			1	1	
9:30 am	62.0 (57.5-70.0)	1		1	1		2		3	4	4	4
1:30 pm	62.6 (58.0-70.0)							3	1	4	8	4
5:30 pm	65.3 (58.1-71.0)	1		2	2	1		1	1	2	6	4

which specimens of the water plant *Ceratophyllum* sp., heavily epiphytized by algae, were exposed to redbelly dace in an aquarium. Algal epiphytes present (identified by Dr. Brook) included:

Division Cyanophyta
  Class Cyanophyceae
    Order Oscillatoriales

Oscillatoria tenuis, *Phormidium molle*, *Anabaena inaequalis*.

Division Chrysophyta
  Class Bacillariophyceae
    Order Centrales

Cyclotella

Order Pennales

Gomphonema, *Hantzschia*, *Navicula*, *Nitzschia acicularis*, *N. palea*, *Synedra radians*.

Division Cryptophyta
  Class Cryptophyceae
    Order Cryptomonadales

Cryptomonas. Note: Smith (1950:626) does not place the Class Cryptophyceae in a specific plant Division, but treats it as a group of uncertain systematic position.

Division Chlorophyta
  Class Chlorophyceae
    Order Volvocales

Chlamydomonas, *Gonium sociale*.

Order Tetrasporales

Apiocystis.

Order Ulotrichales

Stichococcus, *Ulothrix*.

Order Oedogoniales

Oedogonium.

Order Chlorococcales

Ankistrodesmus falcatus var. *acicularis*, *A. falcatus* var. *stipitatus*, *Characium rostratum*, *Coelastrum microporum*, *Crucigenia quadrata*, *Scenedesmus acutiformis*, *S. bijuga*, *S. quadricauda*, *Tetraedron minimum*.

Order Zygnematales

Closterium Leibleinii, *Cosmarium impressulum*, *C. subcrenatum*, *Mougeotia*, *Spirogyra*.

Sprigs of *Ceratophyllum* thickly overgrown by epiphytes were placed in the aquarium with redbelly dace that had been unfed for two days. This was done on five separate occasions, with a different sprig of *Ceratophyllum* used each time. The number of dace present was 22-26. Before each piece of *Ceratophyllum* was placed in the aquarium, the sprig was pressed between absorbent paper towels for 15 minutes and weighed on a Mettler Balance. The *Ceratophyllum* was left in the aquarium for 24 hours, removed, pressed once more between paper towels for 15 minutes, and reweighed.

The redbelly dace were seen to feed from the *Ceratophyllum*, and examination of three intestines confirmed the presence of many of the epiphytes in them. Subsequent examination of the *Ceratophyllum* by Dr. Brook indicated that all of the epiphytes except *Oedogonium* were gone. The average loss in weight was 68.1 percent. Five controls lost an average of 18.1 percent. This indicates that some epiphytes may have dispersed after the treatment given them, but that apparently at least half of the original "standing crop" was consumed (Table 24). It is also of interest that the *Ceratophyllum* sprigs supported epiphytes whose weight was twice as much as their own. The experiment, although subject to laboratory limitations (Moore, 1941:91), indicates that small fishes can exert a profound influence on the populations of suitable food organisms which become available in their environment.

The diet of *C. eos* was not studied in the present investigation. Sibley and Rimsky-Korsakoff (1931:118) found that animal and plant plankton, surface drift, aquatic insects, silt, and higher plants were consumed by this species in the St. Lawrence watershed in New York. Phytoplankton was the most common food noted.

TABLE 24. Amount of epiphytic algae from <u>Ceratophyllum</u> consumed by <u>Chrosomus erythrogaster</u> in an aquarium as measured by weight-loss over a 24-hour period.

	Initial weight (<u>Ceratophyllum</u> plus epiphytic algae)	24-hour weight (<u>Ceratophyllum</u> without epiphytic algae)	% weight lost
	2.203 g	0.686	68.9%
	1.105	0.355	67.9
	2.533	0.803	68.3
	1.408	0.442	68.6
	2.180	0.719	67.0
$\overline{X}$	1.886	0.601	68.1%
24-hour weight-loss in five controls (average)			18.1%
Weight-loss attributable to consumption by fish			50.0%

FAUNAL ASSOCIATIONS

Syntopic Fish Species.

Rivas (1964:43) distinguished between the distributional terms "sympatric" and "syntopic", with "sympatric" referring to "two or more related species which have the same or overlapping geographic distributions, regardless of whether or not they occupy the same macrohabitat (whether or not these species occur together in the same locality)" and "syntopic" referring to "two or more related species which occupy the same macrohabitat."

Brief lists of species associated with *C. erythrogaster* were given by Hemphill (1957:53) and Kendall and Smith (1895:17). The relative frequency with which various other fishes are "syntopic" with northern and southern redbelly dace in Minnesota was determined by compiling species lists of 90 collections of fishes, 40 including *C. erythrogaster* and 50 including *C. eos*, from a variety of localities in the state. The percentage of times a particular species occurred with either *C. erythrogaster* or *C. eos* in these collections was then determined (Table 25).

As shown in Table 25, *C. erythrogaster* and *C. eos* were associated most frequently with other forage fishes that are common in small streams. The five species taken most often with *C. erythrogaster* were

TABLE 25. Fish species associated with *Chrosomus erythrogaster* and *C. eos*, expressed in percent, based on the number of times the species listed were in 50 collections examined containing *C. eos* and 40 containing *C. erythrogaster* from Minnesota.

Family and species	*C. erythrogaster*	*C. eos*
Clupeidae		
Dorosoma cepedianum		2%
Salmonidae		
Salvelinus fontinalis		2
Coregonidae		
Coregonus artedi		6
Umbridae		
Umbra limi		14
Esocidae		
Esox lucius		6
Catostomidae		
Carpiodes cyprinus	2.5%	
Catostomus commersoni	60	64
Hypentelium nigricans	7.5	6
Moxostoma erythrurum	2.5	
Moxostoma sp.	2.5	4
Cyprinidae		
Campostoma anomalum	87.5	6
Chrosomus neogaeus		12
Clinostomus elongatus	5	
Cyprinus carpio	2.5	
Dionda nubila	20	
Hybognathus hankinsoni	42.5	34
Hybopsis biguttata	70	30
Notemigonus crysoleucas		36
Notropis atherinoides		6
N. blennius		4
N. cornutus	100	76
N. dorsalis	95	32

TABLE 25, Continued.

Family and species	C. erythrogaster	C. eos
Cyprinidae (cont.)		
Notropis heterodon		34
N. heterolepis		54
N. hudsonius	2.5	12
N. rubellus	15	
N. spilopterus	7.5	12
N. stramineus	15	8
N. texanus		2
N. umbratilis	30	
N. volucellus		32
Phenacobius mirabilis	7.5	
Pimephales notatus	92.5	34
Pimephales promelas	65	64
Rhinichthys atratulus	67.5	48
Rhinichthys cataractae	17.5	10
Semotilus atromaculatus	80	74
Semotilus margarita	7.5	12
Ictaluridae		
Ictalurus melas	2.5	4
Ictalurus natalis	5	
Ictalurus nebulosus		8
Ictalurus sp.	2.5	
Noturus exilis	2.5	
Noturus flavus	2.5	
Noturus gyrinus	20	18
Gasterosteidae		
Culaea inconstans	22.5	36
Pungitius pungitius		6
Cyprinodontidae		
Fundulus diaphanus		16
Percopsidae		
Percopsis omiscomaycus		2
Centrarchidae		
Ambloplites rupestris	5	10
Lepomis cyanellus	32.5	2
Lepomis gibbosus	2.5	4
Lepomis humilis	2.5	
Lepomis macrochirus	5	4

TABLE 25, Continued.

Family and species	*C. erythrogaster*	*C. eos*
Centrarchidae (cont.)		
Micropterus dolomieui	5	
Micropterus salmoides	5	8
Pomoxis annularis	2.5	
Pomoxis nigromaculatus		4
Pomoxis sp.		2
Percidae		
Etheostoma caeruleum	20	
E. exile	10	40
E. flabellare	57.5	
E. microperca	2.5	4
E. nigrum	92.5	66
E. zonale	5	
Perca flavescens		32
Percina caprodes	2.5	4
Percina maculata	12.5	6
Stizostedion vitreum		8
Sciaenidae		
Aplodinotus grunniens		2
Cottidae		
Cottus bairdi	2.5	2

Notropis cornutus (in 100% of the 40 collections including *C. erythrogaster* that were tabulated), *Notropis dorsalis* (95%), *Pimephales notatus* (92.5%), *Etheostoma nigrum* (92.5%), and *Campostoma anomalum* (87.5%). The five species taken most often with *C. eos* were *Notropis cornutus* (in 76% of the 50 collections including *C. eos* that were tabulated), *Semotilus atromaculatus* (74%), *Etheostoma nigrum* (66%), *Catostomus commersoni* (64%), and *Pimephales promelas* (64%).

Predators and Enemies.

No direct observations of predation on redbelly dace by other animals were made, but such potential predators as the creek chub (*Semotilus atromaculatus*) and the snapping turtle (*Chelydra serpentina*) were found in habitats occupied by both *C. erythrogaster* and *C. eos*.

A decapitated *C. erythrogaster* was seen floating in the headwaters of the Zumbro River, Dodge County, on 19 May 1965. Two individuals were killed by a crayfish (*Orconectes virilis*) in an aquarium at the University of Minnesota. In one of these fish, all the flesh posterior to the head was sheared away.

Concerning the activities of man, Trautman (1957: 328) wrote that redbelly dace are vulnerable to seining, and "in a few hours two commercial bait seiners could capture 75% of the dace population in a half-mile of stream." Streams mentioned by Trautman had reduced populations of *C. erythrogaster* when compared with streams that had been protected from seining. This kind of observation suggests that *C. erythrogaster* was perhaps far more common in the streams of southeastern Minnesota prior to the development of the bait industry.

Parasites.

In comparison to certain fish species with which it is syntopic, *C. erythrogaster* was found to be but lightly parasitized.

The intestines of 150 *C. erythrogaster* taken in the headwaters of the Zumbro River, Dodge County, were examined and no mature internal parasites were found. Three of five *Notropis cornutus* examined from the same locality harbored intestinal tapeworms.

The fishes studied were infested with metacercarial cysts of the trematodes *Clinostomum* sp. and "neascus". *Clinostomum* was relatively rare, but "neascus" occurred in most of the fish species examined in the study area.

Fishes collected in the Zumbro on 19 May 1965 (T105N-R16W-S9/16) and on 16 May 1967 (T105N-R16W-S11/14) were used to determine the extent of "neascus" infestation based on the relative numbers of fish of each species that bore cysts. Only fish species represented by more than 20 individuals were included in Table 26, which indicates that C. erythrogaster was less severely infested than other local fish species.

No attempt was made to determine the intensity of infestation by "neascus" on the basis of the average number of metacercariae per individual. This consideration, while clearly important, would entail counting the "spots" on each fish and was beyond the scope of the present study. However, the intensity of infestation was clearly related directly to the relative numbers of fish of each species bearing cysts. The average number of "spots" in the seven afflicted C. erythrogaster examined was 1.6 (range 1-3), whereas Etheostoma nigrum, Notropis cornutus, Pimephales notatus, and Pimephales promelas were liberally sprinkled.

It is likely that a combination of several factors act to determine the extent to which various fishes and fish species are infested with "neascus".

Large ("old") N. cornutus were found to be generally more heavily parasitized than small (younger) ones. Thus, although relatively complex causes, such as occupation of different microhabitats by young and old fishes of the same species could be involved, it is possible that larger fishes have more cysts simply because they have been exposed to the parasite longer.

Interspecific differences in habitat may also

TABLE 26. Infestation by metacercariae of "neascus" (Trematoda) in certain host species of fishes in the Zumbro River, Dodge County, Minnesota, based on the relative numbers of each host parasitized.

Host	Specimens examined	Number infested	Number not infested	% infested
Chrosomus erythrogaster	250	7	243	2.80
Notropis dorsalis	33	2	31	6.06
Notropis cornutus	135	105	30	77.78
Pimephales promelas	38	30	8	78.95
Pimephales notatus	22	18	4	81.82
Etheostoma nigrum	62	62	0	100.00

influence the degree of infestation. "Neascus" cercariae, which swim to a fish after leaving their previous intermediate host (a snail -- see Olsen, 1962:95), may infest darters (as E. nigrum) which frequently rest on the substrate more easily than they infest fishes that swim about off the bottom most of the time. Another example concerns members of the minnow Genus Rhinichthys. Hunter (1933:255) found "neascus" in fewer specimens of R. cataractae, which inhabits riffles, than in R. atratulus, which is found more frequently in slower moving water.

SUMMARY

1. A taxonomic, distributional, and ecological study of the North American minnows *Chrosomus erythrogaster* and *C. eos* (Osteichthyes: Cyprinidae) was conducted from January, 1965, through September, 1967, at the University of Minnesota.

2. Although some workers have considered *C. eos* as a subspecies of *C. erythrogaster*, these fishes are generally regarded as two species. Intercharacter correlation coefficients of 24 morphological traits, derived by computer for samples of both species from all drainage systems in which each occurs in Minnesota, did not demonstrate strong clinal (i.e., geographic) variation and indicated that two distinct morphological types exist. On this basis relegation of *C. eos* and *C. erythrogaster* to separate species was upheld.

3. The morphological characters most useful for distinguishing *C. erythrogaster* and *C. eos* are "angle of mouth" and ratios among certain head dimensions. In young individuals of both the snout is comparatively short and the mouth upturned. During ontogeny of *C. erythrogaster* the snout attains greater length in relation to length of orbit and length of mouth, and the mouth becomes increasingly less oblique than in *C. eos*. Although overlap occurs, the angle of mouth is

generally less than 55° in C. erythrogaster and more than 55° in C. eos.

4. Sexual variation in general morphology was noted among adults of both species. In C. erythrogaster, pectoral and pelvic fins were significantly larger in males than in females. In C. eos, pectoral, pelvic, dorsal, and anal fins were significantly larger in males.

5. C. eos was noted in all drainage basins (Arctic, Mississippi, Red River, and Superior) in Minnesota. C. erythrogaster is known in Minnesota from only the "lower" Mississippi River basin, below St. Anthony Falls at Minneapolis. C. eos is rare where C. erythrogaster occurs.

6. The ecological phase of the study, conducted primarily with C. erythrogaster in the Zumbro River, Dodge County, emphasized reproduction and diet.

7. C. erythrogaster is a schooling fish, which influences certain aspects of its breeding behavior. "Spawning groups", which left the school to breed, typically consisted of two males and one female, Although spawning was not observed, it is apparent that this species breeds in early summer in Minnesota.

8. Morphological manifestations of breeding season included the development of enlarged gonads (reaching a maximum of approximately 20 percent of total weight

in females and 1.5 percent of total weight in males), scarlet breeding color, and epidermal tubercles. Comparable changes occurred in _C. eos_.

9.Ten adult female _C. erythrogaster_ contained, by actual count, an average of 12,395 eggs (range 5,708-18,888). Gravimetric methods proved most satisfactory for estimating the numbers of eggs present. The enlargement of ovaries in breeding season apparently is accomplished chiefly through increased size of individual ova, although numbers of eggs seemed highest in breeding season as well.

10. Hybrids of _C. erythrogaster_ with the minnows _Notropis cornutus_ and _Dionda nubila_ were noted. The combination of _C. erythrogaster_ x _D. nubila_ has not been previously reported. Several hybrids of _C. eos_ x _C. neogaeus_ were found in the University's fish collection.

11. Although opportunistic when feeding, the _C. erythrogaster_ studied chiefly ate microscopic plant organisms ("algae"). Diatoms (Division Chrysophyta), blue-green algae (Cyanophyta), euglenoids (Euglenophyta), and green algae (Chlorophyta) were the most important dietary items.

12. The _C. erythrogaster_ studied obtained most of their food from bottom ooze in the stream. Feeding

activity was highest around midday in a 20-hour study done in May, 1967. Aquarium specimens removed large amounts of epiphytic algae from vascular plants.

13. *C. erythrogaster* and *C. eos* were commonly associated with other species of fish that prefer small streams, such as the white sucker (*Catostomus commersoni*), creek chub (*Semotilus atromaculatus*), common shiner (*Notropis cornutus*), bigmouth shiner *Notropis dorsalis*), blunthead minnow (*Pimephales notatus*), and Johnny darter (*Etheostoma nigrum*).

14. *C. erythrogaster* was less heavily parasitized than most other fish species with which it was associated. No mature internal parasites were noted in *C. erythrogaster*. Cysts of the trematodes *Clinostomum* sp. ("white grub") and "neascus" (black grub") infested *C. erythrogaster* occasionally.

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APPENDIX

Selected measurements made on specimens from collections of *Chrosomus erythrogaster* and *C. eos* available at the University of Minnesota. Collections listed are arranged numerically within Drainages and River basins as follows:

A. Arctic Drainage.

B. Cedar River basin.

C. Minnesota River basin.

D. Lower Mississippi River basin.

E. Upper Mississippi River basin.

F. Missouri River basin.

G. Red River Drainage.

H. St. Croix River basin.

I. Lake Superior Drainage.

J. Notes on other species in the collections.

Space limitations prevented inclusion of the names of those who made the collections.

APPENDIX A. ARCTIC DRAINAGE

Coll. no.	Locality	Date	Number of specimens measured	$\overline{X}$ total length	$\overline{X}$ orbit length	$\overline{X}$ snout length	$\overline{X}$ mouth length	$\overline{X}$ mouth angle	Identification Orig.	Identification Rev.
18036	Warroad R., about 6 mi. S Roosevelt, Roseau Co.	6-26-55	33	54.3 (51.5-59.8)	3.0 (2.8-3.4)	2.9 (2.7-3.2)	2.5 (2.2-2.8)	60° (55-64)	eos	eos
18128	Clear R., about 20 mi. SW R'sevelt, Lake of the Woods Co.	6-27-55	1	57.1	3.2	3.2	2.8	62	eos	eos
18135	Rose Cr. at Warroad R., about 6 mi. S R'sevelt, Roseau Co.	7-26-55	1	55.5	3.0	2.8	2.5	56	eos	eos
18879	Beetle Lake, Lake Co.	7-16-58	5	43.3 (40.9-43.8)	2.6 (2.5-2.8)	2.4 (2.3-2.5)	2.0 (2.0-2.1)	58 (56-62)	eos	eos
19041	Finn Pond, Lake Co., T60-8-22	10-11-61	1	56.7	3.3	3.1	2.8	56	eos	eos

APPENDIX A. ARCTIC DRAINAGE, Continued.

Coll. no.	Locality	Date	Number of specimens measured	$\bar{X}$ total length	$\bar{X}$ orbit length	$\bar{X}$ snout length	$\bar{X}$ mouth length	$\bar{X}$ mouth angle	Identification Orig.	Identification Rev.
19583	Gypsy Lake, Lake Co., T60-10-6/7	10-19-61	4	64.2 (55.8-72.2)	3.4 (3.0-4.0)	3.4 (2.8-4.0)	3.0 (2.5-3.5)	58° (52-62)	eos	eos
19593	Arrowhead Cr., Lake Co. T61-8-14	7-19-61	1	67.8	3.7	3.6	3.5	60	eos	eos
19744	Lena Lake, Lake Co. T60N-R8-S5/6	-- 64	5	53.6 (48.9-57.9)	3.0 (2.7-3.3)	2.8 (2.4-3.0)	2.6 (2.3-2.8)	59 (56-61)	eos	eos
-	Square Lake, Lake Co. T60-R7-S35	6-19-62	5	51.3 (45.6-55.5)	3.1 (2.8-3.3)	2.8 (2.6-3.0)	2.5 (2.1-2.8)	58 (57-59)	eos	eos
-	Rapid River, trib. of Rainy River	9- 3-62	15	32.5 (26.1-37.8)	2.1 (1.8-2.4)	1.8 (1.4-2.3)	1.6 (1.2-2.4)	57 (53-61)	eos	eos
-	Maniwaki Lake, Lake Co. T62-R6-S3/4	-- 62	5	51.5 (45.0-57.8)	3.1 (2.6-3.3)	2.7 (2.4-2.8)	2.4 (2.1-2.6)	57 (53-61)	eos	eos

APPENDIX B. CEDAR RIVER BASIN

Coll. no.	Locality	Date	Number of specimens measured	$\overline{X}$ total length	$\overline{X}$ orbit length	$\overline{X}$ snout length	$\overline{X}$ mouth length	$\overline{X}$ mouth angle	Identification Orig.	Identification Rev.
10996	outlet Alb't Lea Lake at dam, Freeborn Co.	8- 2-38	2	46.7 (45.7-47.7)	3.0 --	2.6 (2.5-2.7)	2.5 --	?	eryth (distorted)	?
18179	Red Cedar R. Mower Co.	9- 1-54	1	65.0	3.5	3.8	3.0	52°	eryth	eryth
18248	Cedar R., 4 mi. W Lyle, Mower Co.	5-14-55	1 1	64.8 59.9	3.6 3.2	3.5 3.5	3.3 2.8	61 49	eryth eryth	eos eryth
19058	Fountain Lake Cr., Freeborn Co.	8- 2-45	9	39.9 (25.5-55.0)	2.4 (1.7-3.1)	2.1 (1.2-3.1)	2.0 (1.1-2.8)	60 (58-64)	?eos	eos
60010 (Field no.)	Orchard Cr., Mower Co..	8-15-60	5	41.3	2.4	2.3	1.9	52	eos	eryth
60011	Otter Cr., 1 mi. E. Lyle, Mower Co.	8-15-60	7	46.2 (43.2-48.3)	2.6 (2.3-2.8)	2.6 (2.3-2.8)	2.2 (1.9-2.4)	49 (46-53)	eryth	eryth

APPENDIX B. CEDAR RIVER BASIN, Continued.

Coll. no.	Locality	Date	Number of specimens measured	$\bar{X}$ total length	$\bar{X}$ orbit length	$\bar{X}$ snout length	$\bar{X}$ mouth length	$\bar{X}$ mouth angle	Identification Orig.	Identification Rev.
60012	Rose Cr., Mower Co.	8-16-60	5	44.4 (43.2-46.3)	2.4 (2.3-2.5)	2.4 (2.3-2.7)	2.0 (1.8-2.3)	51° (48 53)	eryth	eryth
60013	Little Cedar R., at Hwy 56, Mower Co.	8-16-60	5	40.1 (39.0-41.4)	2.3 (2.2-2.4)	2.1 (2.0-2.3)	1.8 (1.7-2.0)	54 (51-55)	eryth	eryth
60015	Beaver Cr., 1 mi. N Hwy 56, Fillmore Co.	8-16-60	5	44.9 (43.8-46.2)	2.6 (2.5-2.8)	2.5 (2.4-2.6)	2.1 (2.0-2.3)	54 (51-55)	eryth	eryth
64027	Otter Cr. at Co. Rd. 6, Mower Co.	10-24-64	184	59.2 (28.1-82.6)	3.1 (2.0-4.0)	3.3 (1.3-5.0)	2.8 (1.3-4.3)	49 (43-55)	eryth	eryth
64030	Cedar R. at Orchard Cr., Mower Co.	10-24-64	36	65.6 (29.8-82.4)	3.3 (1.8-4.1)	3.3 (1.5-4.9)	not measured		eryth	eryth
64031	Cedar R. at Hwy 25, Mower Co.	10-24-64	5	68.4 (61.6-73.4)	3.2 (3.1-3.4)	4.0 (3.6-4.3)	3.2 (2.9-3.4)	50 (48-52)	eryth	eryth

APPENDIX C. MINNESOTA RIVER BASIN

Coll. no.	Locality	Date	Number of specimens measured	$\bar{X}$ total length	$\bar{X}$ orbit length	$\bar{X}$ snout length	$\bar{X}$ mouth length	$\bar{X}$ mouth angle	Identification Orig.	Identification Rev.
18233	Credit R., Savage, Scott Co.	5-15-54	34	63.7 (52.7-70.8)	3.4 (3.0-3.8)	3.5 (3.0-4.0)	3.1 (2.5-3.8)	59° (53-65)	eos	eos
18234	Nine Mile Creek, Hennepin Co.	9 -- 54	32	59.6 (54.0-66.1)	3.3 (3.0-3.5)	3.3 (2.8-3.8)	2.9 (2.6-3.3)	59 (56-63)	eos	eos
18237	Credit R. at Hidden Valley above Savage, Scott Co.	4-16-55	5	61.9 (60.5-63.0)	3.5 (3.5-3.6)	3.3 (3.1-3.4)	3.0 (2.8-3.3)	58 (55-61)	eos	eos
18238	Credit R. at Savage, Scott Co.	4-16-55	10	59.6 (54.5-66.7)	3.3 (3.2-3.5)	3.0 (2.8-3.4)	2.9 (2.7-3.2)	58 (54-62)	eos	eos
18241	1st creek W Credit R. on Prior Lake Road, Scott Co.	4-25-55	6	51.7 (45.1-56.5)	3.2 (2.8-3.5)	3.0 (2.6-3.3)	2.6 (2.2-3.0)	56 (53-61)	eos	eos

APPENDIX C. MINNESOTA RIVER BASIN, Continued.

Coll. no.	Locality	Date	Number of specimens measured	$\bar{X}$ total length	$\bar{X}$ orbit length	$\bar{X}$ snout length	$\bar{X}$ mouth length	$\bar{X}$ mouth angle	Identification Orig.	Identification Rev.
18244	Credit R., Savage, Scott Co.	6-19-54	19	56.9 (47.7-66.3)	3.2 (2.7-3.7)	3.2 (2.5-3.8)	2.7 (2.4-3.5)	58° (51-61)	?eos	eos
18246	Minneopa Cr, W of Mankato, Blue Earth Co.	7-31-54	6	56.6 (53.6-62.0)	3.2 (3.0-3.4)	3.0 (2.7-3.4)	2.7 (2.5-3.0)	62 (59-63)	?eos	eos

APPENDIX D. LOWER MISSISSIPPI RIVER BASIN

Coll. no.	Locality	Date	Number of specimens measured	$\bar{X}$ total length	$\bar{X}$ orbit length	$\bar{X}$ snout length	$\bar{X}$ mouth length	$\bar{X}$ mouth angle	Identification Orig.	Identification Rev.
10997	S. Br. Root R., Fillmore Co.	6 -- 38	5	58.9 (40.7-73.2)	3.1 (2.4-3.7)	3.3 (2.4-4.2)	2.8 (2.1-3.5)	52° (48-56)	sp.	eryth
14122	Lake Pepin	7-31-40	1	66.6	3.5	3.3	3.0	62	eos	eos
16009	Pine Cr., Fillmore Co.	6-19-48	5	75.7 (73.4-78.0)	3.8 (3.7-3.9)	4.4 (4.2-4.5)	3.6 (3.3-4.0)	48 (45-51)	eryth	eryth
18067	Rush Cr., Houston Co.	7 -- 45	2	69.5 (67.2-71.8)	3.4 -	4.1 (3.9-4.4)	3.2 (3.1-3.5)	45 (44-45)	eryth	eryth
18176	Little Cannon R., Cannon Falls, Goodhue Co., T111N-R18W-S36	5-29-54	4	76.4 (72.5-80.5)	3.6 (3.5-3.7)	4.4 (4.2-4.7)	3.4 (3.3-3.5)	48 (45-50)	?eos	eryth
18177	N. Br. Zumbro R., Rice Co., 109N-19W-11/12	6-13-53	2	47.1 (32.5-61.6)	2.7 (2.0-3.3)	2.6 (1.8-3.4)	2.3 (1.6-3.0)	52 (49-55)	eryth	eryth

APPENDIX D. LOWER MISSISSIPPI RIVER BASIN, Continued.

Coll. no.	Locality	Date	Number of specimens measured	$\overline{X}$ total length	$\overline{X}$ orbit length	$\overline{X}$ snout length	$\overline{X}$ mouth length	$\overline{X}$ mouth angle	Identification Orig.	Identification Rev.
18235	Zumbro R., Rice Co., T109N-19W-S12	7-28-52	6	46.4 (41.6-54.7)	2.7 (2.5-2.9)	2.4 (2.2-2.8)	2.2 (1.8-2.6)	59° (55-62)	eos	eos
			14	47.6 (40.6-59.8)	2.8 (2.5-3.1)	2.5 (2.2-3.2)	2.2 (1.9-2.8)	55 (50-58)	eos	eryth
18236	Zumbro R., Rice Co., T109N-19W-9	7-28-52	17	62.2 (51.5-66.5)	3.3 (2.9-3.6)	3.5 (3.0-3.9)	2.9 (2.5-3.2)	48 (44-51)	eos	eryth
18239	B Br Zumbro R., Goodhue Co., 110N-17W-32/33	6-13-53	1	46.5	2.8	2.4	2.1	52	eryth	eryth
18240	Little Cannon R., Cannon Falls, Goodhue Co.	5-29-54	1	44.0	2.6	2.5	2.2	53	eos	eryth
18242	N Br Zumbro R., Wanamingo, Goodhue Co.	5-31-54	1	51.3	2.8	3.0	2.7	49	?eos	eryth

APPENDIX D. LOWER MISSISSIPPI RIVER BASIN, Continued.

Coll. no.	Locality	Date	Number of specimens measured	$\overline{X}$ total length	$\overline{X}$ orbit length	$\overline{X}$ snout length	$\overline{X}$ mouth length	$\overline{X}$ mouth angle °	Identification Orig.	Identification Rev.
18243	Belle Cr., Goodhue Co.	8- 3-54	2	51.2 (47.3-55.0)	3.0 (2.8-3.2)	2.9 (2.6-3.2)	2.6 (2.4-2.7)	53 (50-55)	?eos	eryth
18247	S Br Zumbro R., Dodge Co.	6-24-54	1	41.3	2.4	2.3	2.1	54	sp.	eryth
18870	N Br Zumbro R., Goodhue Co., 110N-18W-25	5- 7-55	62	39.2 (27.8-47.2)	2.3 (1.8-2.6)	2.2 (1.5-2.6)	1.9 (1.2-2.3)	51 (45-57)	eryth	eryth
19055	N. fork Whitewater R., Winona Co., T107N-R10-59	7-19-46	4	62.3 (58.9-69.3)	3.2 (2.9-3.4)	3.7 (3.3-4.1)	3.0 (2.9-3.1)	49 (45-52)	eryth	eryth
19056	Etna Cr., E fork Root R., Fillmore Co.	8-20-43	21	58.1 (45.4-71.7)	3.1 (2.5-3.4)	3.2 (2.5-4.2)	2.8 (2.2-3.6)	51 (44-55)	eryth	eryth
19057	S Br Creek, trib to Root R., Fillmore Co.	8-20-43	22	43.3 (33.5-61.6)	2.8 (2.0-3.5)	2.4 (1.7-3.3)	2.2 (1.7-3.0)	57 (52-62)	?eos	eos

APPENDIX D. LOWER MISSISSIPPI RIVER BASIN, Continued.

Coll. no.	Locality	Date	Number of specimens measured	$\overline{X}$ total length	$\overline{X}$ orbit length	$\overline{X}$ snout length	$\overline{X}$ mouth length	$\overline{X}$ mouth angle	Identification Orig.	Identification Rev.
19074	Rush Cr., Fillmore Co.	7- 5-45	3	60.1 (43.4-71.5)	3.1 (2.4-3.5)	3.5 (2.6-4.1)	2.7 (2.3-3.1)	52° (49-53)	eryth	eryth
65001	Dodge Center Cr., Dodge Co. T107-R17	5-19-65	5	40.1 (37.7-42.4)	2.3 (2.1-2.5)	2.2 (2.0-2.3)	1.9 (1.7-2.0)	53 (51-54)	eryth	eryth
66018	Camp Cr., Preston, Fillmore Co.	10-12-66	2	64.8 (59.5-70.0)	3.2 (3.0-3.3)	3.9 (3.6-4.1)	3.2 (3.0-3.3)	49 (48-49)	eryth	eryth
-	Belle Cr., Welch, Goodhue Co.	10- 6-64	3	40.9 (33.9-51.9)	2.2 (2.0-2.6)	2.3 (1.9-3.0)	2.0 (1.6-2.6)	47 (45-49)	eryth	eryth
-	Belle Cr., Goodhue Co., T113N-R16W-S21	10- 8-64	11	35.3 (24.8-44.4)	2.2 (1.7-2.6)	2.0 (1.4-2.4)	1.7 (1.3-2.1)	53 (50-56)	eryth	eryth
-	N Br Zumbro R., at Kenyon	10-15-64	5	35.0 (33.0-37.1)	2.1 (1.9-2.3)	1.9 (1.8-2.1)	1.6 (1.5-1.8)	52 (50-54)	eryth	eryth

APPENDIX E. UPPER MISSISSIPPI RIVER BASIN

Coll. no.	Locality	Date	Number of specimens measured	$\overline{X}$ total length	$\overline{X}$ orbit length	$\overline{X}$ snout length	$\overline{X}$ mouth length	$\overline{X}$ mouth angle	Identification Orig.	Identification Rev.
10628	Long Prairie R, S Motley, Morrison-Crow Wing Co's.	9-11-39	1	51.2	3.0	2.5	2.5	63°	eos	eos
10629	Red Eye R., E Sebecka, Wadena Co.	9-12-39	2	35.3 (32.7-37.8)	2.2 (2.0-2.4)	1.7 (1.5-1.8)	1.5 (1.3-1.7)	61 (60-63)	eos	eos
10630	Rum R., Onamia, Mille Lacs Co.	9- 5-39	5	38.2 (33.4-42.7)	2.4 (2.3-2.4)	1.9 (1.7-2.1)	1.8 (1.5-2.0)	59 (56-62)	eos	eos
10634	O'Neal Bk. at Hwy 69, Mille Lacs Co.	7-19-39	1	51.7	3.2	2.6	2.4	56	eos	eos
10635	Crow R., 2 mi. below Watertown, Wright Co.	10-24-39	4	51.4 (42.7-58.4)	3.1 (2.7-3.3)	2.9 (2.4-3.1)	2.4 (1.9-2.8)	59 (57-60)	eos	eos
10637	Rum R., Anoka, Anoka Co.	7-18-39	8	46.2 (26.5-59.0)	2.7 (1.9-3.4)	2.4 (1.3-3.0)	2.2 (1.4-2.8)	60 (55-65)	eos	eos
10638	Mosquito Cr. near Motley	9-13-39	1	55.3	3.0	2.9	2.5	58	eos	eos

APPENDIX E. UPPER MISSISSIPPI RIVER BASIN, Continued.

Coll. no.	Locality	Date	Number of specimens measured	$\overline{X}$ total length	$\overline{X}$ orbit length	$\overline{X}$ snout length	$\overline{X}$ mouth length	$\overline{X}$ mouth angle	Identification Orig.	Identification Rev.
13854	Middle Nicollet Lake, Itasca Park	8-10-41	5	48.9 (45.4-54.8)	3.0 (2.8-3.2)	2.7 (2.4-3.3)	2.4 (2.2-2.6)	61° (60-62)	eos	eos
13856	Nicollet Cr, Itasca Park	8-10-41	3	57.8 (54.5-60.6)	3.5 (3.3-3.8)	3.0 (2.4-3.5)	2.7 (2.4-2.9)	61 (60-64)	eos	eos
14225	Lake Frances, Wright Co.	5-31-40	2	58.2 (56.9-59.4)	3.1 (3.0-3.1)	3.0 -	2.9 -	61 -	eos	eos
14858	Nicollet Cr, Itasca Park	5-29-37	1	33.5	2.1	1.9	1.8	52	eos	eos
18147	Miss'ppi R., Itasca Park	7-14-54	5	56.9 (52.2-63.1)	3.2 (2.9-3.5)	3.2 (3.0-3.6)	2.9 (2.6-3.3)	59 (56-61)	eos	eos
19602	Long Lake, Clearwater Co.	7-27-61	5	55.4 (49.7-64.5)	3.2 (2.9-3.7)	3.0 (2.4-3.5)	2.6 (2.2-3.1)	57 (51-62)	eos	eos
19662	Lake Itasca, Clearwater Co.	-- 62	5	49.2 (48.2-50.2)	3.1 (2.8-3.2)	2.6 (2.4-2.8)	2.4 (2.3-2.4)	57 (55-60)	eos	eos

APPENDIX E. UPPER MISSISSIPPI RIVER BASIN, Continued.

Coll. no.	Locality	Date	Number of specimens measured	$\bar{X}$ total length	$\bar{X}$ orbit length	$\bar{X}$ snout length	$\bar{X}$ mouth length	$\bar{X}$ mouth angle	Identification Orig.	Identification Rev.
19702	Mississippi headwaters, Itasca Park	summer, '62	5	57.2 (54.0-61.8)	3.1 (3.0-3.3)	3.1 (2.9-3.3)	2.8 (2.6-3.2)	58° (56-60)	eos	eos
63010	Lower LaSalle Bk, Hubbard Co.	7-13-63	5	41.0 (38.7-42.5)	2.4 (2.3-2.5)	2.1 (2.0-2.3)	2.0 (1.8-2.0)	61 (60-62)	eos	eos
64006	Mississippi headwaters, Itasca Park	6-22-64	60	53.8 (50.1-57.1)	3.0 (2.7-3.2)	2.8 (2.5-3.2)	2.6 (2.2-3.0)	60 (55-66)	eos	eos
64010	Mississippi headwaters, Itasca Park	7-30-64	5	57.3 (54.6-60.0)	3.2 (2.9-3.3)	2.9 (2.8-3.1)	3.0 (2.8-3.2)	59 (58-61)	eos	eos
66007	Dinner Cr., Becker Co.	8-12-66	1	53.8	3.0	3.0	2.5	57	eos	eos
-	Straight R., 4 mi S Park Rapids	7-22-65	5	40.8 (38.3-42.6)	2.5 (2.3-2.6)	2.2 (2.0-2.4)	2.0 (1.8-2.1)	60 (57-64)	eos	eos
-	Deming Lake, Itasca Park, Hubbard Co., T143N-R35W-S30	July 4-7 1967	5	51.5 (48.2-54.6)	3.1 (2.9-3.3)	2.8 (2.7-3.0)	2.4 (2.2-2.6)	56 (52-60)	eos	eos

APPENDIX F. MISSOURI RIVER BASIN.

Coll. no.	Locality	Date	Number of specimens measured	$\bar{X}$ total length	$\bar{X}$ orbit length	$\bar{X}$ snout length	$\bar{X}$ mouth length	$\bar{X}$ mouth angle	Identification Orig.	Identification Rev.
18245	Kanaranzi Cr., W of Adrian, Nobles Co.	10- 2-54	7	46.8 (43.4-49.7)	2.5 (2.4-2.6)	2.6 (2.5-2.7)	2.2 (2.0-2.3)	50° (48-52)	?eos	eryth

APPENDIX G. RED RIVER DRAINAGE

Coll. no.	Locality	Date	Number of specimens measured	$\bar{X}$ total length	$\bar{X}$ orbit length	$\bar{X}$ snout length	$\bar{X}$ mouth length	$\bar{X}$ mouth angle	Identification Orig.	Identification Rev.
18071	Middle R., U.S. 75, Argyle, Marshall Co.	7- 5-55	4	54.9 (52.8-58.6)	2.9 (2.8-3.0)	2.8 (2.6-3.0)	2.5 (2.3-2.7)	60° (58-61)	eos	eos
18127	Ottertail R., outlet Finger Lakes	6-21-55	1	51.1	3.0	2.8	2.4	54	eos	eos
18130	Moose R., 10 mi. N, 5 mi. E Grygla, Beltrami Co.	6-27-55	5	60.3 (56.8-65.4)	3.2 (3.0-3.5)	3.1 (3.0-3.4)	2.9 (2.7-3.0)	57 (55-60)	eos	eos
18132	Mud R, 0.2 mi. below Grygla, Marshall Co.	6-27-55	30	53.8 (51.5-56.8)	3.0 (2.8-3.3)	2.8 (2.5-3.1)	2.5 (2.3-2.8)	59 (51-64)	eos	eos
18133	Int'mtnt pools below dam, U.S. Wildfowl ref., Marshall Co.	6-27-55	1	48.7	2.8	2.4	2.3	56	eos	eos
18134	Ottertail R., outlet Height of Land Lake, Becker Co.	6-30-55	1	43.1	2.5	1.9	2.0	60	eos	eos

APPENDIX G. RED RIVER DRAINAGE, Continued.

Coll. no.	Locality	Date	Number of specimens measured	$\bar{X}$ total length	$\bar{X}$ orbit length	$\bar{X}$ snout length	$\bar{X}$ mouth length	$\bar{X}$ mouth angle	Identification Orig.	Identification Rev.
18139	Mud Lake refuge, pool below control dam, Marshall Co.	6-21-55	11	49.3 (30.6-59.7)	2.8 (1.8-3.1)	2.7 (1.9-3.1)	2.6 (2.2-2.8)	58° (55-62)	eos	eos
19575	Wild Rice R., Clearwater Co, T145-37-31	7- 9-63	5	48.8 (47.6-49.8)	2.9 (2.8-3.0)	2.6 (2.5-2.8)	2.4 (2.4-2.5)	55 (54-57)	eos	eos
19703	Lawndale Cr., Wilkin Co.	-- 61	5	51.9 (38.2-57.9)	3.0 (2.4-3.3)	2.7 (2.0-3.1)	2.4 (1.9-2.8)	55 (53-58)	eos	eos
19706	Twin Lake, Nay-tah-waush, Mahnomen Co.	7-10-62	5	42.3 (38.7-51.7)	2.6 (2.4-3.0)	2.2 (1.9-2.7)	1.9 (1.7-2.5)	54 (52-57)	eos	eos
63006	Hier Cr., Clearwater Co.	7- 5-63	5	41.1 (38.7-43.0)	2.6 (2.5-2.7)	2.2 (1.9-2.4)	2.0 (1.8-2.0)	59 (56-61)	eos	eos
64008	stream bet. N and S Twin Lakes, Mah'men Co.	6-23-64	5	48.0 (46.5-48.1)	2.7 (2.5-2.8)	2.7 (2.5-2.8)	2.3 (2.2-2.5)	57 (55-60)	eos	eos
64015	Wild Rice R., Clearwater Co.	7- 7-64	5	52.7 (49.0-56.3)	3.2 (3.0-3.3)	3.0 (2.8-3.2)	2.7 (2.6-2.9)	59 (54-62)	eos	eos

APPENDIX G. RED RIVER DRAINAGE, Continued.

Coll. no.	Locality	Date	Number of specimens measured	$\bar{X}$ total length	$\bar{X}$ orbit length	$\bar{X}$ snout length	$\bar{X}$ mouth length	$\bar{X}$ mouth angle	Identification Orig.	Identification Rev.
-	Sucker Br., Clearwater Co.	7-26-60	5	44.0 (41.7-46.4)	2.5 (2.4-2.6)	2.4 (2.2-2.6)	2.2 (2.1-2.3)	60° (58-62)	eos	eos
-	Whiskey Cr., Clay Co., T137-R45	8- 5-65	5	47.8 (37.8-54.8)	2.8 (2.4-3.2)	2.6 (2.1-3.0)	2.3 (1.7-2.7)	62 (58-64)	?eos	eos

APPENDIX H. ST. CROIX RIVER BASIN

Coll. no.	Locality	Date	Number of specimens measured	$\bar{X}$ total length	$\bar{X}$ orbit length	$\bar{X}$ snout length	$\bar{X}$ mouth length	$\bar{X}$ mouth angle	Identification Orig.	Identification Rev.
14148	Gar tank, [Stillwater] Washington Co.	11 -- 37	1	61.4	3.5	3.2	2.8	62°	eos	eos
60001	Rock Cr., Chisago Co.	6-27-60	5	48.8 (45.7-51.3)	2.8 (2.7-2.9)	2.5 (2.2-2.8)	2.2 (2.0-2.4)	59 (57-62)	eos	eos

APPENDIX I. LAKE SUPERIOR DRAINAGE

Coll. no.	Locality	Date	Number of specimens measured	$\bar{X}$ total length	$\bar{X}$ orbit length	$\bar{X}$ snout length	$\bar{X}$ mouth length	$\bar{X}$ mouth angle	Identification Orig.	Identification Rev.
10631	small lake near Poplar Lake, Cook Co.	6-28-35		(Disintegrated)					eos	?
10632	Temperance R., Cook Co.	7-30-36	1	56.1	3.2	3.2	2.7	55°	eos	eos
10633	Brule Lake, Cook Co.	7- 9-35	5	49.9 (47.3-52.4)	2.8 (2.6-3.0)	2.7 (2.3-3.0)	not measured		eos	eos
11510, 11, 15, 19	Lester R., St. Louis Co.	Jul 5-Aug 10, 1940	5	56.8 (51.2-60.0)	3.1 (2.9-3.3)	2.8 (2.5-3.0)	2.6 (2.3-2.8)	57 (55-59)	eos	eos
11512-17	French R., near mouth, St. Louis Co.	Jul 16-Jul 18, 1940	5	55.6 (51.9-59.4)	3.1 (2.8-3.3)	2.8 (2.5-2.9)	2.5 (2.3-2.6)	59 (56-63)	eos	eos
11513	Beaver R., small trib, Lake Co.	7-26-40	26	33.4 (28.6-38.4)	2.0 (1.9-2.3)	1.7 (1.4-2.0)	1.6 (1.3-1.8)	60 (55-66)	eos	eos
11514-17	Knife R., St. Louis-Lake Co's.	6-27-40	5	54.1 (42.4-66.0)	3.1 (2.5-4.0)	2.7 (2.1-3.4)	2.5 (1.8-3.0)	58 (53-62)	eos	eos

APPENDIX I. LAKE SUPERIOR DRAINAGE, Continued

Coll. no.	Locality	Date	Number of specimens measured	$\overline{X}$ total length	$\overline{X}$ orbit length	$\overline{X}$ snout length	$\overline{X}$ mouth length	$\overline{X}$ mouth angle	Identification Orig.	Identification Rev.
11518	Baptism R., Lake Co.	8- 2-40	10	38.2 (33.6-45.6)	2.4 (2.3-2.8)	2.0 (1.7-2.3)	1.8 (1.5-2.1)	59° (57-62)	eos	eos
11520	Lester R., St. Louis Co.	7- 5-40	5	55.0 (51.5-59.8)	3.2 (3.0-3.5)	2.8 (2.5-3.2)	2.6 (2.5-2.9)	59 (55-61)	eos	eos
12059	Temperance R., Cook Co.	7-15-41	2	46.9 (44.0-49.7)	2.6 (2.5-2.8)	2.4 (2.3-2.6)	2.1 (2.1-2.2)	57 (56-58)	eos	eos
12091	Arrowhead R., Cook Co.	8-21-41	5	44.1 (40.4-45.6)	2.5 (2.4-2.6)	2.2 (1.9-2.5)	2.1 (1.7-2.4)	61 (60-63)	eos	eos
12161	Devil's Track R., Cook Co.	8-14-41	1	37.6	2.2	1.9	1.8	60	eos	eos
12173	Cascade R., Cook Co.	8- 6-41	5	30.1 (29.0-31.9)	2.2 (2.0-2.3)	1.5 (1.4-1.6)	1.5 (1.5-1.6)	56 (52-58)	eos	eos
12189	Devil's Track R., Cook Co.	8-19-41	1	49.8	3.0	2.8	2.5	54	eos	eos

APPENDIX I. LAKE SUPERIOR DRAINAGE, Continued.

Coll. no.	Locality	Date	Number of specimens measured	$\overline{X}$ total length	$\overline{X}$ orbit length	$\overline{X}$ snout length	$\overline{X}$ mouth length	$\overline{X}$ mouth angle	Identification Orig.	Identification Rev.
13283	Temperance R., Cook Co.	7- 8-41	1	54.9	3.3	3.1	2.7	53°	eos	eos
13289	Cascade R., Cook Co.	9- 9-41	9	48.7 (41.3-53.1)	2.7 (2.3-2.9)	2.5 (2.2-2.7)	2.3 (1.9-2.5)	59 (57-61)	eos	eos
13308	Two Island R., Lake Co.	6-26-41	10	52.4 (38.0-65.0)	2.9 (2.3-3.6)	2.7 (2.0-3.4)	not measured		eos	eos
13375	Kadunce Cr., Cook Co.	9-15-41	10	41.7 (36.0-49.0)	2.5 (2.6-2.8)	2.0 (1.7-2.3)	2.0 (1.8-2.2)	60 (53-65)	eos	eos
13428	Kimball Cr., Cook Co.	9- 4-41	5	38.6 (32.3-42.7)	2.4 (2.2-2.6)	2.0 (1.7-2.3)	1.8 (1.4-2.0)	58 (51-64)	eos	eos
14612	Murphy Cr., St. Louis Co.	-- 46	1	59.2	3.5	3.0	2.7	60	eos	eos
14835	French R., St. Louis Co.	8-26-46	5	48.9 (43.4-60.3)	2.9 (2.6-3.5)	2.5 (2.2-3.0)	2.3 (1.9-2.8)	57 (54-60)	eos	eos

APPENDIX I. LAKE SUPERIOR DRAINAGE, Continued.

Coll. no.	Locality	Date	Number of specimens measured	$\bar{X}$ total length	$\bar{X}$ orbit length	$\bar{X}$ snout length	$\bar{X}$ mouth length	$\bar{X}$ mouth angle	Identification Orig.	Identification Rev.
14863	French R., St. Louis Co. T52-R13-S28	8-27-46	5	56.2 (53.4-62.3)	3.3 (3.1-3.4)	3.0 (2.8-3.3)	2.7 (2.5-2.9)	56° (54-58)	eos	eos
19054	Kadunce Cr. at mouth, Cook Co.	9- 5-41	5	34.6 (32.5-37.0)	2.3 (2.4-2.5)	1.9 (1.8-2.0)	1.6 (1.5-1.7)	55 (52-58)	eos	eos
19114	Split Rock River	7- 9-55	4	42.0 (39.2-45.1)	2.5 (2.4-2.6)	2.2 (2.1-2.4)	2.0 (1.8-2.1)	58 (56-59)	eos	eos

APPENDIX J. NOTES ON OTHER SPECIES IN COLLECTIONS OF *C. ERYTHROGASTER* AND *C. EOS*

Coll. no.	Locality	Remarks
ARCTIC DRAINAGE:		
18036	(see Appendix A)	Contains 115 *C. eos*, 1 *Pimephales promelas*, and 1 *Culaea inconstans*.
18128	(see Appendix A)	Contains 1 *C. eos* and 26 *C. neogaeus*.
19593	(see Appendix A)	Contains 1 *C. eos* and 1 *C. neogaeus*.
UPPER MISSISSIPPI RIVER BASIN:		
10636	Mille Lacs Lake	The single specimen is *Semotilus margarita*.
RED RIVER DRAINAGE:		
18129	N fork, 30 mi S Warroad (int'sctn 3 counties), Beltrami Co.	The seven specimens are *C. neogaeus*.
18131	pool below control dam, Mud Lake refuge, Marshall Co.	The 48 specimens are *C. neogaeus*.
18132	(see Appendix G)	Contains 35 *C. eos* and 1 *C. neogaeus*.
18133	(see Appendix G)	Contains 1 *C. eos* and 1 (?)*C. neogaeus*.

APPENDIX J. OTHER SPECIES IN COLLECTIONS, Continued.

LAKE SUPERIOR DRAINAGE.

Coll. no.	Locality	Remarks
11520	(see Appendix I).	Contains 40 *C. eos* and 2 *C. neogaeus*.
12091	(see Appendix I)	Contains 22 *C. eos*, 3 *C. neogaeus*, 1 F_1 hybrid between them, and 6 specimens that are morphologically intermediate between *C. eos* and F_1 hybrids.
12173	(see Appendix I)	Contains 11 *C. eos* and 2 *C. neogaeus*.
12189	(see Appendix I)	Contains 1 *C. eos* and 1 *C. neogaeus*.
13289	(see Appendix I)	Contains 9 *C. eos*, 1 *C. neogaeus*, 1 F_1 hybrid between them, and 1 specimen that is morphologically intermediate between *C. eos* and F_1 hybrids.
13308	(see Appendix I)	Contains 17 *C. eos* and 2 *C. neogaeus*.
13375	(see Appendix I)	Contains 17 *C. eos* and 11 *C. neogaeus*.
14104	Rock Cr., trib Gooseberry R., Lake Co.	The 2 specimens are *C. neogaeus*.
14835	(see Appendix I)	Contains 17 *C. eos* and 1 *C. neogaeus*.
14863	(see Appendix I)	Contains 9 *C. eos* and 3 *C. neogaeus*.

APPENDIX J. OTHER SPECIES IN COLLECTIONS, Continued.

LAKE SUPERIOR DRAINAGE (Continued).

Coll. no.	Locality	Remarks
19114	(see Appendix I)	Contains 4 *C. eos* and 1 *C. neogaeus*.
19311	Arrowhead Cr., Lake Co.	The single specimen is *C. neogaeus*.